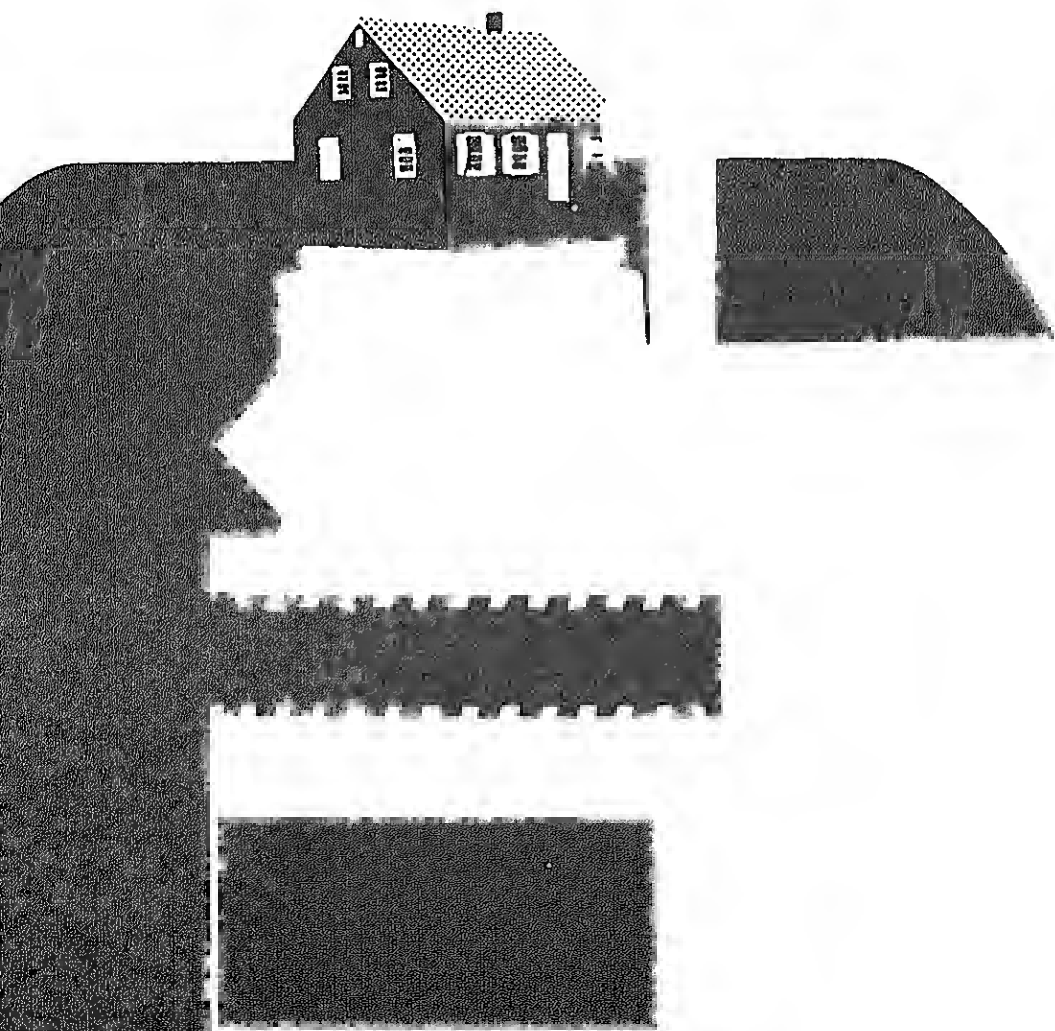




# Medial Measures for Houses Damaged by Expansive Clay



REMEDIAL MEASURES FOR  
HOUSES DAMAGED BY  
EXPANSIVE CLAY

April 5, 1978

by

The University of Texas at Arlington  
Under Contract No. H-2240-R

for

U.S. Department of Housing and Urban Development  
Office of Policy Development and Research

## FOREWORD

This report addresses a housing problem that is most prevalent in the southwestern region of the United States; cracking of floors and walls caused by swelling and shrinking of the soil on which the house is built. Laboratory and field investigations of five repair techniques on damaged houses in two geologic formations composed primarily of expansive clay are documented in the study. Results of a 2-year evaluation of the effectiveness of the various techniques indicate that damage caused by swelling and shrinking can be minimized by treating the soil and foundation as an interactive system.

The information contained in this report should be of use both to homeowners and to professionals who must recommend repair procedures to homeowners. It was developed with the assistance of three Government Officials: William J. Werner (deceased), Conrad Arnolds, and Donald J. Morony.



Donna E. Shalala  
Assistant Secretary for Policy  
Development and Research

## ACKNOWLEDGMENTS

This research documents the performance of certain remedial measures which could be utilized as repair techniques, along with other actions, to repair homes damaged by the vertical movement of expansive clay soils. The magnitude of movement is associated with the type of clay minerals in the soil and seasonal climatic conditions.

The University of Texas at Arlington is indebted to the Department of Housing and Urban Development for sponsoring this, and parallel research, which may be utilized to refine repair procedures to restore homes and light buildings which are in a damaged condition. The Southwestern United States has climatic conditions which allow the shrink and swell tendencies of expansive soils to develop with devastating effect. However, other areas of the United States and the world are not immune. Even if the soil moisture conditions be significantly altered in other areas, soils include clay minerals of the montmorillonite group, volume changes of the soils may be expected. Damaged to man-made structures may range from unsightly cracks to facilities which are structurally unsound. The destructive mechanism is a time-dependent process unlike damage associated with a natural disaster. However, costs of repair or replacement may be as great or greater. Fortunately, unlike a natural disaster, the loss or destruction associated with expansive soils does usually not involve loss of life.

Many individuals have contributed to this research during various stages or throughout the project duration. While it is impossible to recognize everyone associated with this research, there are those whose efforts contributed immeasurably. These individuals include:

- Mr. Henry F. (Jeff) Ball, H.U.D., Dallas Area Office, Dallas, Texas
- Mr. Paul J. Wright, Vice President, Woodbine Corporation, Fort Worth, Texas
- Mr. Ernest L. Buckley, Professor of Architecture
- Mrs. Judith B. Corley, Civil Engineering Graduate Student
- Mr. William J. Howard, Civil Engineering Graduate Student
- Mr. James M. Sims, Civil Engineering Graduate Student
- Mr. Abbas Mehdibeghi, Civil Engineering Graduate Student
- Mr. Weerapun Sriboonlue, Civil Engineering Graduate Student

Special recognition must be given to Mr. Wallace A. Clines, Technical Staff Assistant, whose special abilities and unstinting hours did much to insure timely completion of each project phase. To all other people who in any way contributed to this research, the author expresses his sincere appreciation.

Mr. William J. Werner, P. E., (deceased), Office of Policy Development and Research, Department of Housing and Urban Development, served as Government Technical Representative until May 5, 1978. Mr. Conrad A. Werner became the Government Technical Representative and served during the remainder of the research period.

Arthur R. Poor, Ph.D., P.E.  
Professor of Civil Engineering

## PREFACE

his report is subject to the following limitations:

1. The two year time span of the data collection is rather short.
2. There is additional data collection in progress which could possibly alter the conclusions regarding the effectiveness of the techniques studied.
3. Caution should be exercised in drawing general conclusions based upon a single experiment. Each remedial procedure was tried only once in each geologic formation.
4. Successful application of any of these remedies depends heavily upon the knowledge and skill of the contractor. Not only is it necessary to determine the correct quantity of water to be added, but also the proper locations for adding the water. For example, cupped and domed slabs would be treated differently.

Figures	ix
Tables	xii
t	xiv
ve Summary	xvi

# 1 INTRODUCTION

PURPOSE AND SCOPE . . . . .	1
BACKGROUND . . . . .	2

# 2 MOISTURE-TEMPERATURE CHARACTERISTICS OF SUBSURFACE SOIL

MOISTURE-TEMPERATURE CELL INSTALLATION LOCATIONS . . . . .	4
MONITORING MOISTURE-TEMPERATURE CHANGES . . . . .	4
LABORATORY CALIBRATION . . . . .	4
COMPUTER CALIBRATION . . . . .	5
SUBSURFACE MOISTURE-TEMPERATURE DATA ACQUISITION . . . . .	8

# 3 LIME SLURRY INJECTION

GENERAL . . . . .	21
HOUSE LOCATIONS . . . . .	21
VERTICAL MOVEMENT . . . . .	21
3.3.1 830 N.E. 32nd Street, Grand Prairie, Texas . . . . .	21
3.3.2 2710 Cary Drive, Mesquite, Texas . . . . .	23
3.3.3 Comparison of Vertical Movement . . . . .	23
SOIL MOISTURE-TEMPERATURE CHARACTERISTICS . . . . .	29
3.4.1 830 N.E. 32nd Street, Grand Prairie, Texas . . . . .	33
3.4.2 2710 Cary Drive, Mesquite, Texas . . . . .	33
3.4.3 Comparison of Moisture-Temperature Characteristics . . . . .	34
EVALUATION OF LIME SLURRY PRESSURE INJECTION FOR STABILIZATION . . . . .	40

# 4 MOISTURE MIGRATION BARRIERS

GENERAL . . . . .	42
GRANULAR CAPILLARY BARRIER . . . . .	43
4.2.1 VERTICAL MOVEMENT - 1642 Cedar Keys Drive, Lewisville, Tx. . . . .	43
4.2.2 VERTICAL MOVEMENT - 9909 Bluffcreek, Dallas, Texas . . . . .	45
4.2.3 COMPARISON OF VERTICAL MOVEMENTS . . . . .	51
4.2.4 SOIL MOISTURE-TEMPERATURE CHARACTERISTICS - 1642 Cedar Keys Drive, Lewisville, Texas . . . . .	51



- 4.2.5 SOIL MOISTURE-TEMPERATURE CHARACTERISTICS -  
9909 Bluffcreek Drive, Dallas, Texas . . . . .
- 4.2.6 COMPARISON OF MOISTURE-TEMPERATURE CHARACTERISTICS . . . . .
- 4.3 RECYCLED RUBBER IMPERVIOUS BARRIERS . . . . .
- 4.3.1 VERTICAL MOVEMENT - 461 Sweetbriar Drive, Lewisville, Texas . . . . .
- 4.3.2 VERTICAL MOVEMENT - 1314 Athens Street, Mesquite, Texas . . . . .
- 4.3.3 COMPARISON OF VERTICAL MOVEMENTS . . . . .
- 4.3.4 SOIL MOISTURE-TEMPERATURE CHARACTERISTICS -  
461 Sweetbriar Drive, Lewisville, Texas . . . . .
- 4.3.5 SOIL MOISTURE-TEMPERATURE CHARACTERISTICS -  
1314 Athens Street, Mesquite, Texas . . . . .
- 4.3.6 COMPARISON OF SOIL MOISTURE-TEMPERATURE CHARACTERISTICS . . . . .
- 4.4 LEAN CONCRETE MOISTURE BARRIERS . . . . .
- 4.4.1 VERTICAL MOVEMENT - 1137 Eastwood Drive, Dallas, Texas . . . . .
- 4.4.2 VERTICAL MOVEMENT - 4204 Culmer, Balch Springs, Texas . . . . .
- 4.4.3 COMPARISON OF VERTICAL MOVEMENTS . . . . .
- 4.4.4 SOIL MOISTURE-TEMPERATURE CHARACTERISTICS -  
1137 Eastwood Drive, Lewisville, Texas . . . . .
- 4.4.5 SOIL MOISTURE-TEMPERATURE CHARACTERISTICS -  
4204 Culmer, Balch Springs, Texas . . . . .
- 4.4.6 COMPARISON OF SOIL MOISTURE-TEMPERATURE CHARACTERISTICS . . . . .
- 4.5 EVALUATION OF VERTICAL MOISTURE MIGRATION BARRIERS . . . . .

## Section 5 SUBSURFACE IRRIGATION SYSTEMS

- 5.1 GENERAL . . . . .
- 5.2 INSTALLATION . . . . .
- 5.2.1 VERTICAL MOVEMENT - 5807 Fess Street, Dallas, Texas . . . . .
- 5.2.2 VERTICAL MOVEMENT - 3513 Heath Street, Mesquite, Texas . . . . .
- 5.2.3 COMPARISON OF VERTICAL MOVEMENTS . . . . .
- 5.2.4 SOIL MOISTURE-TEMPERATURE CHARACTERISTICS -  
5807 Fess Street, Dallas, Texas . . . . .
- 5.2.5 SOIL MOISTURE-TEMPERATURE CHARACTERISTICS -  
3513 Heath Street, Mesquite, Texas . . . . .
- 5.2.6 COMPARISON OF MOISTURE-TEMPERATURE CHARACTERISTICS . . . . .
- 5.3 EVALUATION OF SUBSURFACE IRRIGATION SYSTEM STABILIZATION . . . . .

## Section 6 SUMMARY AND CONCLUSIONS

- 6.1 SUMMARY . . . . .
- 6.2 CONCLUSIONS . . . . .

## Section 7 APPENDIX

Moisture Cell Calibration Curve	11
9909 Bluffcreek, Dallas, Texas	12
461 Sweetbriar Drive, Lewisville, Texas	13
4204 Culmer, Balch Springs, Texas	14
1137 Eastwood Drive, Lewisville, Texas	15
1314 Athens Street, Mesquite, Texas	16
3513 Heath Street, Mesquite, Texas	17
2710 Cary Drive, Mesquite, Texas	18
1642 Cedar Keys Drive, Lewisville, Texas	19
5807 Fess Street, Dallas, Texas	20
830 N.E. 32nd Street, Grand Prairie, Texas	
Vertical Movement of Slab Perimeter	22
830 N.E. 32nd Street, Grand Prairie, Texas	
Differential Elevation on Slab Perimeter	24
830 N.E. 32nd Street, Grand Prairie, Texas	
Vertical Movement of Slab Perimeter	26
2710 Cary Drive, Mesquite, Texas	
Differential Elevation on Slab Perimeter	27
2710 Cary Drive, Mesquite, Texas	
Maximum Perimeter Differential Movement Comparison of Lime Slurry Injection on Different Geologic Formations	30
Soil Moisture Content - Lime Slurry Injection	35
830 N.E. 32nd Street, Grand Prairie, Texas	
Soil Temperature Variation	36
830 N.E. 32nd Street, Grand Prairie, Texas	
Soil Moisture Content - Lime Slurry Injection	38
2710 Cary Drive, Mesquite, Texas	
Soil Temperature Variation	39
2710 Cary Drive, Mesquite, Texas	
Vertical Movement of Slab Perimeter	44
1642 Cedar Keys Drive, Lewisville, Texas	
Differential Elevation on Slab Perimeter	46
1642 Cedar Keys Drive, Lewisville, Texas	
Vertical Movement of Slab Perimeter	48
9909 Bluffcreek, Dallas, Texas	

- 24 Maximum Perimeter Differential Movement Comparison  
Capillary Barrier on Different Geologic Formations
- 25 Soil Moisture Content - Capillary Barrier  
1642 Cedar Keys Drive, Lewisville, Texas
- 26 Soil Temperature Variation  
1642 Cedar Keys Drive, Lewisville, Texas
- 27 Soil Moisture Content - Capillary Barrier  
9909 Bluffcreek, Dallas, Texas
- 28 Soil Temperature Variation  
9909 Bluffcreek, Dallas, Texas
- 29 Vertical Movement of Slab Perimeter  
461 Sweetbriar Drive, Lewisville, Texas
- 30 Differential Elevation on Slab Perimeter  
461 Sweetbriar Drive, Lewisville, Texas
- 31 Vertical Movement of Slab Perimeter  
1314 Athens Street, Mesquite, Texas
- 32 Differential Elevation on Slab Perimeter  
1314 Athens Street, Mesquite, Texas
- 33 Maximum Perimeter Differential Movement Comparison  
Rubber Barrier on Different Geologic Formations
- 34 Soil Moisture Content - Rubber Barrier  
461 Sweetbriar Drive, Lewisville, Texas
- 35 Soil Temperature Variation  
461 Sweetbriar Drive, Lewisville, Texas
- 36 Soil Moisture Content - Rubber Barrier  
1314 Athens Street, Mesquite, Texas
- 37 Soil Temperature Variation  
1314 Athens Street, Mesquite, Texas
- 38 Vertical Movement of Slab Perimeter  
1137 Eastwood Drive, Lewisville, Texas

Vertical Movement of Slab Perimeter 4204 Culmer, Balch Springs, Texas	86
Differential Elevation on Slab Perimeter 4204 Culmer, Balch Springs, Texas	87
Maximum Perimeter Differential Movement Comparison of Concrete Barrier on Different Geologic Formations	89
Soil Moisture Content - Lean Concrete Barrier 1137 Eastwood Drive, Lewisville, Texas	93
Soil Temperature Variation 1137 Eastwood Drive, Lewisville, Texas	94
Soil Moisture Content - Lean Concrete 4204 Culmer, Balch Springs, Texas	97
Soil Temperature Variation 4204 Culmer, Balch Springs, Texas	99
Vertical Movement of Slab Perimeter 5807 Fess Street, Dallas, Texas	106
Differential Elevation on Slab Perimeter 5807 Fess Street, Dallas, Texas	107
Vertical Movement of Slab Perimeter 3513 Heath Street, Mesquite, Texas	109
Differential Elevation on Slab Perimeter 3513 Heath Street, Mesquite, Texas	110
Maximum Perimeter Differential Movement Comparison of Different Geologic Formations Subsurface Irrigation System	113
Soil Moisture Content - Subsurface Irrigation System 5807 Fess Street, Dallas, Texas	116
Soil Temperature Variation 5807 Fess Street, Dallas, Texas	117
Soil Moisture Content - Subsurface Irrigation System 3513 Heath Street, Mesquite, Texas	119
Soil Temperature Variation 3513 Heath Street, Mesquite, Texas	120

- 1 Endpoints for Calibration Curve
- 2 Data Points per Sample
- 3 Differential Elevation  
830 N.E. 32nd Street, Grand Prairie, Texas
- 4 Differential Elevation  
2710 Cary, Mesquite, Texas
- 5 Maximum Perimeter Differential Movement  
830 N.E. 32nd Street, Grand Prairie, Texas
- 6 Maximum Perimeter Differential Movement  
2710 Cary, Mesquite, Texas
- 7 Temperature Means and Standard Deviation  
830 N.E. 32nd Street, Grand Prairie, Texas
- 8 Temperature Means and Standard Deviation  
2710 Cary Drive, Mesquite, Texas
- 9 Differential Elevation  
1642 Cedar Keys, Lewisville, Texas
- 10 Differential Elevation  
9909 Bluffcreek, Dallas
- 11 Maximum Perimeter Differential Movement  
1642 Cedar Keys, Lewisville, Texas
- 12 Maximum Perimeter Differential Movement  
9906 Bluffcreek, Dallas, Texas
- 13 Temperature Means and Standard Deviation  
1642 Cedar Keys Drive, Lewisville, Texas
- 14 Temperature Means and Standard Deviation  
9909 Bluffcreek, Dallas, Texas
- 15 Differential Elevation  
461 Sweetbriar Drive, Lewisville, Texas
- 16 Differential Elevation  
1314 Athens, Mesquite, Texas
- 17 Maximum Perimeter Differential Movement

Maximum Perimeter Differential Movement 1314 Athens, Mesquite, Texas	72
Temperature Means and Standard Deviation 461 Sweetbriar Drive, Lewisville, Texas	76
Temperature Means and Standard Deviation 1314 Athens Street, Mesquite, Texas	76
Differential Elevation 1137 Eastwood, Lewisville, Texas	85
Differential Elevation 4204 Culmer, Balch Springs, Texas	88
Maximum Perimeter Differential Movement 1137 Eastwood, Lewisville, Texas	90
Maximum Perimeter Differential Movement 4204 Culmer, Balch Springs, Texas	91
Temperature Means and Standard Deviation 1137 Eastwood, Lewisville, Texas	96
Temperature Means and Standard Deviation 4204 Culmer, Balch Springs, Texas	96
Vertical Moisture Barrier Performance Summary (January 1978)	101
Differential Elevation 5807 Fess Street, Dallas, Texas	108
Differential Elevation 3513 Heath, Mesquite, Texas	111
Maximum Perimeter Differential Movement 5807 Fess Street, Dallas, Texas	114
Maximum Perimeter Differential Movement 3513 Heath, Mesquite, Texas	115
Temperature Means and Standard Deviation 5807 Fess Street, Dallas, Texas	118
Temperature Means and Standard Deviation 3513 Heath, Mesquite, Texas	118

## A B S T R A C T

Remedial Measures for Houses Damaged by Expansive Clay Soil. Laboratory and field investigations of various repair techniques on two geologic formations whose residual soils are predominately clay. Five damaged homes on each formation were identified and stabilization techniques utilized for the foundation soils. The homes had concave and convex curvatures, with corresponding damage reflected in the superstructure.

The effectiveness of various repair techniques to mitigate change in underlying soils with the slab and subsoil acting as a unit were evaluated. Materials and equipment commonly available in the construction industry were utilized.

Moisture-temperature cells were installed in boreholes at each side of the house slab and calibrated for existing soil conditions. Leveling points were inserted around the slab perimeter, with variations referred to a permanent bench mark. Bench marks were established at each of the ten homes for accurate determination of slab differential settlements. Data acquisition of soil moisture, temperature, and volume change was continued over four seasonal climatic cycles, or approximately years.

Results indicated damage to a home resulting from foundation swelling and shrinking can be minimized by treating the slab and soil as an interacting system. By establishing the water content of the soil at 2-3 percent above the Plastic Limit of the soil and isotropy of the soil mass or maintaining this moisture content, the volume change due to seasonal weather cycles would be reduced to a minimum.

expansive clay soils in the Southwest United States and in the Dallas - Fort Worth Metroplex are detrimental to successful design and behavior of single family residences and other light construction constructed on concrete slabs-on-ground. The combination of expansive clay deposits containing significant quantities of Montmorillonite and a semi-arid climate permit volume changes in the soil which can permanently damage or result in a structurally unsound residence.

This report documents the behavior of 10 residences at various locations in the Dallas - Fort Worth Metroplex. All houses were identified by the D. Dallas Area Office and were selected from a group of H.U.D. houses that showed evidence of foundation/superstructure failure due to soil movements. Five houses were founded upon the Eagle Ford formation, and the other five were founded upon the Taylor Marl formation, both very active soils. Other reports which are considered relevant to the information contained herein are:

"Interim Report of Remedial Measures for Houses Damaged by Expansive Clay," October, 1975 (HUD - PDR - 131).

"Interim Report of Remedial Measures for Houses Damaged by Expansive Clay," November 1976 (HUD - PDR - 172-(a)).

The same remedial technique was utilized for houses located on the different geologic formations. Five different techniques were utilized to achieve effective use of commonly available materials and equipment to bring a house to a useable condition.

Two distressed houses on different geologic formations were used to determine the effectiveness of utilizing high pressure lime slurry injection procedures to stabilize the foundation soil.

Two houses utilized a vertical capillary barrier of coarse lime-inhibitor to inhibit or minimize moisture migration.

Two houses utilized a vertical barrier of lean concrete to isolate foundation mass and mitigate moisture migration.

Two houses utilized a vertical barrier made from a formulation of cement and ground-up rubber tires to inhibit moisture movement.

Two houses utilized a buried subsurface irrigation system to maintain a stable moisture content in the subsoil.



The subsurface soils at each house were instrumented with temperature cells in a borehole located approximately one foot from the house wall. The first instrument was located approximately at the perimeter beam and another instrument placed every 18 inches. In all, four instruments were installed. The borings were located at the corners of each side of the house (16 instruments per house).

Permanent leveling inserts were placed in the perimeter of each house to determine vertical movements with time. All elevations are referred to a permanent bench mark installed in the project area.

Data acquisition and evaluation has continued for two years, covering two seasonal climatic cycles. In this minimal time period, certain conclusions are given.

a. The addition of water to foundation soils will not eliminate prior movements associated with shrink and swell action.

b. Vertical barriers which isolate a substantial soil mass are useful techniques to restore damaged homes to a useable condition. One of the most useful techniques with the barrier is the desirability of raising the moisture content of the subsoil approximately 2-3 percent above the soil plastic limit.

c. For fissured expansive clay soils, data indicate that the pressure lime slurry injection techniques are not a competitive stabilization technique.

d. Passive systems for soil stabilization are desirable. Frequently, the use of a subsurface irrigation system should not be recommended further at the present state-of-the-art.

This research study was made possible by the Office of Planning and Research, Department of Housing and Urban Development. Data collection will be continued for another year or two additional climatic cycles to broaden the data base at which time an updated report will be prepared. Further data acquisition will be dependent upon instrument limitations. Rates thus far have been minimal.

# REMEDIAL MEASURES FOR HOUSES DAMAGED

## BY EXPANSIVE CLAY

### Section 1

#### INTRODUCTION

#### POSE AND SCOPE

s report is in response to the requirements specified as item 1  
ports of Work, Final Reports, Phase 1 and 2, Attachment 1, to Contract  
; "Contract for Research and Demonstration of Remedial Measures and  
Foundation Design of Houses on Expansive Clay Soils."

vious reports documenting actions of this research project and which  
ntial references to this final report are:

"Interim Report of Remedial Measures for Houses Damaged by  
e Clay," October, 1975(1) This report documented results of  
d tasks in the referenced Statement of Work, as follows:

Task 2 required field sampling of the soils in the vicinity of  
each of the 10 houses.

Task 3 activities included laboratory support and determination  
of soil properties.

Task 4 included the field surveys for existing conditions of the  
dwelling, installing instrumentation, installing leveling points  
around the house perimeter and for installation of a permanent  
bench mark for data reference.

"Interim Report of Remedial Measures for Houses Damaged by  
e Clay," November, 1976(2). This report documented results of  
d tasks in the referenced Statement of Work, as follows:

Task 5 required stabilizing the foundation soil utilizing high  
pressure lime slurry injection procedures. Two distressed houses  
on two different geologic expansive soil formations were considered.

Task 6 activities included the use of different type barriers to  
minimize moisture migration. For two different geologic formations,

sisting of coarse sand and gravel. Two houses had a vertical moisture barrier composed of lean concrete, and two houses utilized a vertical moisture barrier made from a formula of asphalt and ground-up rubber tires.

3. Task 7 involved maintaining a stable moisture content of foundation soil by means of a subsurface irrigation system. Two houses on two different geologic expansive soil formations were considered.

This final report documents the results of Phase I. Included are the acquisition, analysis, and performance parameters of the various stabilization techniques used in limiting the volume change in expansive soils subjected to climatic moisture and temperature cycles.

The primary objective of Phase I of this research contract was to investigate various remedial techniques which could be used to return houses damaged by foundation movements to a useable condition. The proposed techniques must demonstrate effective use of commonly available materials, equipment presently manufactured and/or having a capacity for being modified, and being economically justified on a long term basis. It has been established that the stabilization of expansive clay soils is necessary to accomplish this objective. The soil stabilization program is anticipated to limit volumetric change in the subsoil caused by seasonal climatic cycles.

## 1.2 BACKGROUND

The work that is being carried out under this contract was motivated by developments in applied structural and geotechnical theory that have been made by the Construction Research Center at the University of Texas at Austin. The cooperative efforts of the Civil Engineering Department and the Department of Architecture, in close coordination with some of the leading home builders in the Dallas Fort Worth metropolitan area, have produced a better understanding of the factors that contribute to foundation performance.

Phase I of the research contract involved corrective measures taken on a carefully selected sample of 10 existing H.U.D. owned houses showing evidence of foundation/superstructure failure due to seasonal soil movements. All houses were identified by the H.U.D., Dallas Area Office. Five houses were founded upon the Eagle Ford Shale formation, and the other five upon the Taylor Marl formation; both very active soils. Both formations consist of residual clay soils from the Geologic Gulf series of the Cretaceous. They are neritic marine deposits. Volcanic materials were prominent at the time and were widespread at many levels.

The residual clay soils were highly plastic and possessed the capacity for large volume change with changes of climate and soil moisture. These undesirable features were stipulated parameters for selection of the ten houses tested.

Remedial measures that could be used by the owner of an existing house to correct structural distress, or to apply as a part of a repair project, have been evaluated and performance data over two years given. Phase II of this contract provides performance data on experimental foundation design and construction.

## 2.1 MOISTURE-TEMPERATURE CELL INSTALLATION LOCATIONS<sup>(1)</sup>

Moisture-temperature cells were installed in four borings for ten test houses. The north (or most northerly) boring was always numbering continued consecutively, clockwise around the house. A boring code was used during field operations to insure correct location. The first character was the boring number as previously described. The second character was an upper case letter representing the compass direction corresponding to the boring number. The third character was the moisture-temperature cell number. The moisture-temperature cell numbers ranged from Number 1 to Number 4. As an example: 4W2 corresponds to boring number 4, west house and instrument number 2, which was 2.5 feet below the grade. In addition to these borings, a fifth instrumented boring was made at the site selected for treatment by the lime slurry-pressure injection process. These borings were made outside the perimeter of the injection grid and on the sunny west side of the house.

## 2.2 MONITORING MOISTURE-TEMPERATURE CHANGES

The installation of moisture-temperature cells allowed continuing monitoring of the subsoil moisture and temperature changes at the perimeter of the test houses. Initial moisture contents were determined at all locations before beginning any corrective measures. Data acquisition for moisture-temperature and vertical movement of foundation soil continued through approximately four seasonal cycles or March, 1978. Comparative data analysis was used to determine the effectiveness of each soil stabilization technique.

## 2.3. LABORATORY CALIBRATION

Individual moisture-temperature cell calibration curves were determined for each of the 10 house locations in the Phase I portion of the project. Calibration was performed simultaneously for the 11 slabs in the Phase I portion of the project. Undisturbed three inch cores were obtained from the field at the same depths that the moisture-temperature cells were installed and were placed in a "jig" and split longitudinally using a moisture-temperature cell. A moisture-temperature cell was placed between the two halves of the core and the core was then securely vised back together. A sample from the core was then taken to determine the initial moisture content, and the sample was weighed to determine dry weight could be calculated. The core was then securely taped with tape and placed inside a nylon mesh cut to fit the length of the core. This insured a confining effect while allowing for uniform evaporation.

The core was submerged in distilled water for about 48 hours to allow for complete saturation of the soil, and at the end of this period, the excess water was removed from the leads and nylon mesh. The sample was then weighed to determine the moisture content and a resistance reading was made on the cell.

The sample was allowed to air dry for approximately four hours, and a period of 20 hours was allotted for equalization of the moisture content of the sample.

During the equilization period, the core was stored in a controlled humidity environment. After the moisture equilization period, the core was weighed to determine the moisture content, and resistance and temperature readings were taken. The resistance readings generally increased with decreasing moisture content.

The pattern of air drying, equalizing, and resistance readings was repeated until the maximum resistance reading for the ohmmeter was obtained or until further drying was likely to cause excessive spalling of the soil upon removal. The samples were generally recycled if the moisture content dropped more than five percent. At this point, the core was submerged for 48 hours, and a new drying cycle was begun.

At least two, and usually three or more, cycles of wetting and drying were performed for every core. The decision to stop readings on a core was based on the ohmmeter calibration output. A total of 24 cores was used in producing calibration curves for the 10 sites in Phase I.

## COMPUTER CALIBRATION

Previous work with moisture temperature cell calibration indicated that calibration curves resulted in a linear semi log plot for each log cycle when resistance was plotted on the logarithmic scale and moisture content on the arithmetic scale.

The linear line segments for each log cycle were fit using the method of least squares. The two defining equations for a least squares curve are:

$$\sum_{i=1}^n y_i = nk_0 + k_1 \sum_{i=1}^n x_i$$

$$\sum_{i=1}^n x_i y_i = k_0 \sum_{i=1}^n x_i + k_1 \sum_{i=1}^n x_i^2$$

$y$  is the moisture content at the next highest log boundary,  $x$  is equal to

$$k_1 = MC(J+1) - k_0$$

The values of  $k_0$  and  $k_1$  can be used to define a straight line using data of daily calculated moisture content resistance readings. These values are called A1 and A2 and were equal to the following:

$$A1 = \frac{(\sum MC_i^2) - (\sum Resist_i^2) - (\sum Resist_i \times MC_i) (\sum Resist_i)}{(\text{Number of Points}) (\sum Resist)^2 - (\sum Resist)^2}$$

$$A2 = \frac{(\text{Number of Points})(\sum Resist_i \times MC_i) - (\sum MC_i)(\sum Resist_i)}{(\text{Number of Points}) (\sum Resist)^2 - (\sum Resist)^2}$$

The moisture content at the boundaries of each log cycle of squares straight line could then be calculated. The higher end square line was equal to  $A1 + A2 * (I + 1)$  and the lower end was  $A1 + A2 * I$  is the power of ten for the log cycle being considered.

The general sequence of the calibration program CALIB was:

1. Read in the number of data points in each log cycle, being  $10^6$  and the lowest  $10^2$ .
2. Test to see if there were any data points in the first  $10^6$ . If not, test the next log cycle, and continue until a cycle having data is found. Calculate the values of the straight line for this data at the two endpoints.
3. Go to the next lower log cycle and fit the least squares line. Calculate the values at the two end points. Continue until all log cycles have been completed.
4. Average the values at the end points for which two values were calculated. For example, if there were data points in the first  $10^6$  then  $1 \times 10^6$  is the lower limit of this cycle and a value for moisture content at this point would have been calculated based on the first cycle.

the range  $10^6$ . However,  $1 \times 10^6$  is also the upper limit for data points in the log cycle  $10^5$ , so a value of moisture content would have been calculated based on data in the range  $10^5$ . These two values would have been averaged so that a single curve made up of connected straight line segments was obtained.

5. The 95% prediction interval was approximated as being  $2 \times \text{sigma}$  for data in each log cycle. The end points of the prediction interval were also end justified by averaging.

Output consisted of the values of the end points based on the least square fit, the end justified values of moisture content and the log boundary, the upper and lower limits of the prediction interval at the log boundary. Additional calculations were necessary in order to plot the calibration curve.

Laboratory calibration was continued for a core until the computer calibration indicated that the recycling process was fairly stable. This was done using the program CALIB for data from each drying cycle and comparing the results for each log boundary. Errors in input and poor soil contact between the cell and the core could usually be detected from the computer results. For example, Table 1 shows the end points obtained from Sample # 23, Lewisville Phase I. The variation in end points obtained for cycle 1 is attributed to poor contact between the cell and the core for the first cycle.

The problem of sample size was a continuing problem, with the smallest number of samples being in the range of  $10^1$  and  $10^2$ , and  $10^6$ . More deviation between cycles was tolerated for these end points than for those having large sample sizes. Table 1 indicates the number of data points per log cycle for a house location for the samples used on Phase I and the number of drying cycles before an individual sample was considered stable.

Also listed in Table 2 is the number of days of data collection per core. The average number of days represented almost 3.5 months, and this excessive calibration period required readings to be taken 7 days per week.

The variation in values obtained from the various cores was attributed to the following factors:

1. Limited sample size and deviation in sample size.
2. Variation in sample material with depth. Samples were located at depths between 0.5' and 13.5', and all were taken from the same borehole.
3. Some samples showed poor contact between the cell and the soil for the initial cycle.
4. Slaking of material was noted in cases where the core became excessively wet.



Based on prior experience in the calibration of the moisture and temperature cells, satisfactory laboratory calibration can be obtained by subjecting the cells into which the cells have been implanted to cycles of saturation and drying. The results obtained by use of a program such as a CALIB were useful in terminating individual core calibrations and in plotting the final results.

Time requirements for laboratory calibration and by the limited accuracy of the field installed cell would limit their use except in large installations where data was available concerning the failure rate of the field cells, or on the variability in field readings due to cell characteristics.

## 5 SUBSURFACE MOISTURE-TEMPERATURE DATA ACQUISITION

The acquisition of data was planned to coincide with the acquisition of elevation data. Plug in connectors were installed in weather proof boxes on each side of the house foundation, and the instrument leads from the borings beneath the center of the house were carried to one side of the foundation. Data was acquired by using a read-out box modified to accommodate the number of instruments in each borehole. The data, given in resistance values, were recorded and reduced to meaningful values of moisture and temperature in the laboratory.

The master Calibration Curves for the 10 houses included in Phase I of the project are given in Figures 1 through 10. The variation of soil moisture and temperature with time and depth below the slab grade beam will be discussed in the section relating to the particular stabilization technique used.

# ENDPOINTS FOR CALIBRATION CURVE

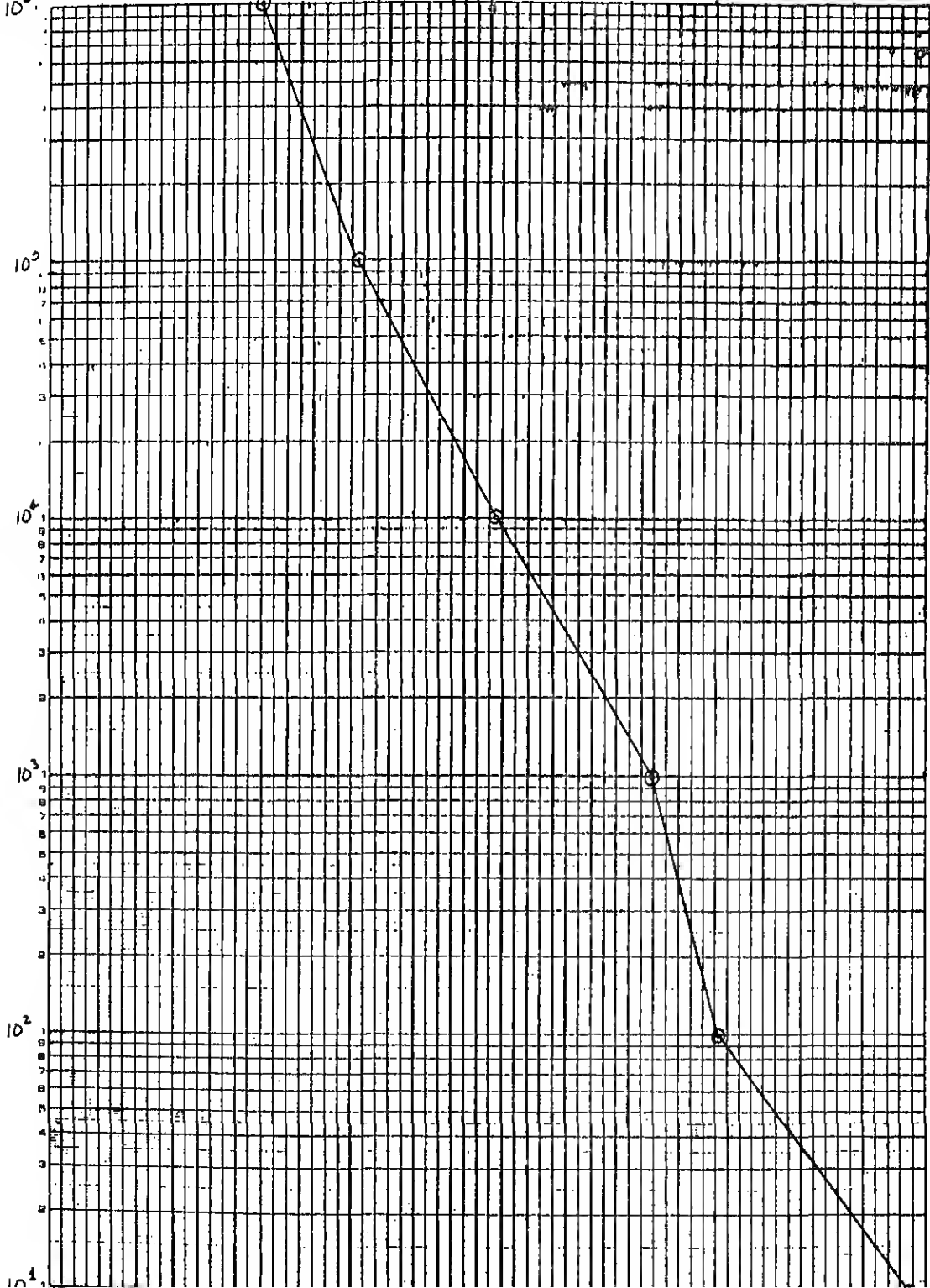
Sample #23 Eastwood St., Lewisville

Depth 4.5 - 6.0 ft.

<u><math>10^6</math></u>	<u><math>10^5</math></u>	<u><math>10^4</math></u>	<u><math>10^3</math></u>	<u><math>10^2</math></u>	<u>Cycle #</u>
0.00	1.73	6.80	21.05	27.67	1
3.52	14.34	18.60	24.21	28.80	2
4.78	12.15	18.92	25.57	28.99	3
4.16	11.81	18.63	25.98	28.90	4
3.95	8.80	11.88	23.90	28.53	Combined

# DATA POINTS PER SAMPLE

Location	Sample #	$10^6$	$10^5$	$10^4$	$10^3$	$10^2$	Cycles
Eastwood Lewisville	12	17	20	14	18	6	3
	23	18	30	35	32	15	4
	33	4	4	1	2	2	1
Cedar Keys, Lewisville	13	29	46	18	14	6	3
	24	39	46	26	29	15	6
Sweetbriar Lewisville	14	38	34	41	14	12	4
	25	0	57	11	12	9	2
Cary Drive Mesquite	15	21	38	15	12	6	3
	26	17	40	24	22	8	3
Heath Street Mesquite	16	21	47	17	12	5	4
	27	23	47	14	15	12	5
Athens Street Mesquite	18	16	46	32	19	10	5
	32	27	30	7	11	9	4
Fess Street Dallas	4	12	29	26	20	16	4
	5	23	54	18	11	4	2
	6	19	42	15	24	6	6
N.E. 32nd St. Grand Prairie	9	16	30	15	14	7	4
	10	43	45	27	20	12	5
	11	21	55	24	30	9	5
Culmer Street Balch Springs	17	29	47	21	23	8	5
	31	25	19	14	13	9	3
Bluffcreek Dallas	19	14	32	15	18	8	4
	28	31	61	17	5	11	2
	34	20	14	5	9	5	2
Average Number of Samples Per Location :							2
Average Number of Days Per Sample :							104
Average Number of Cycles Per Sample :							3



Resistance (Ohms)

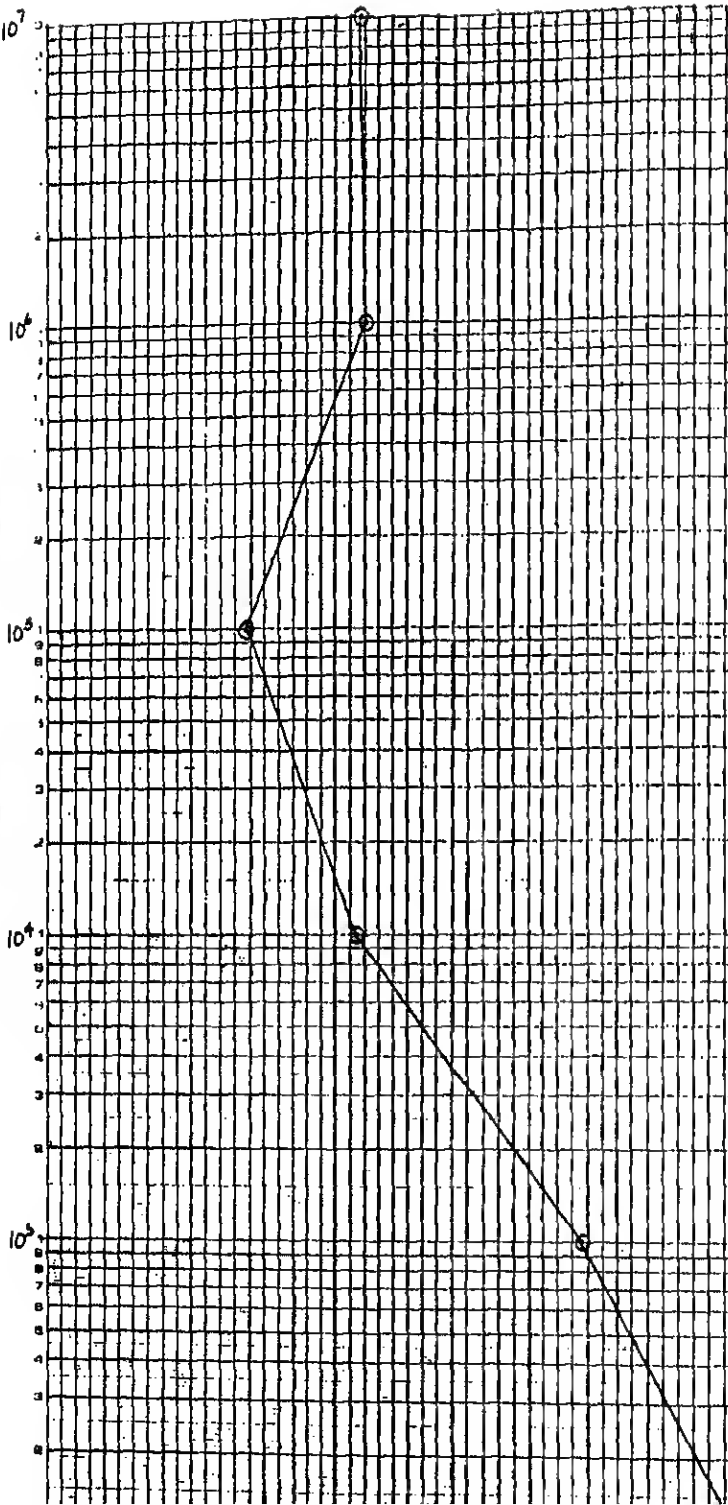
$10^7$

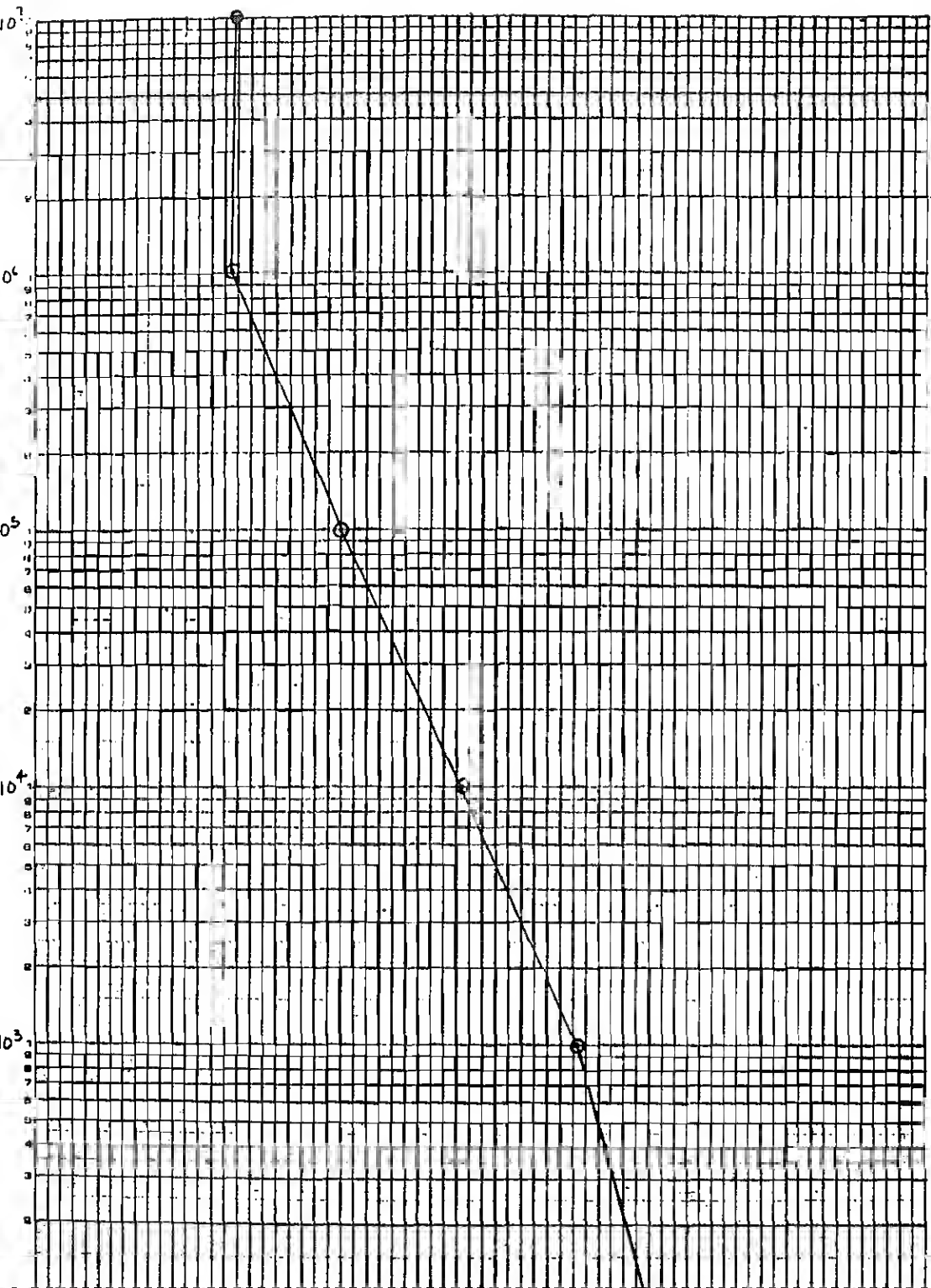
$10^6$

$10^5$

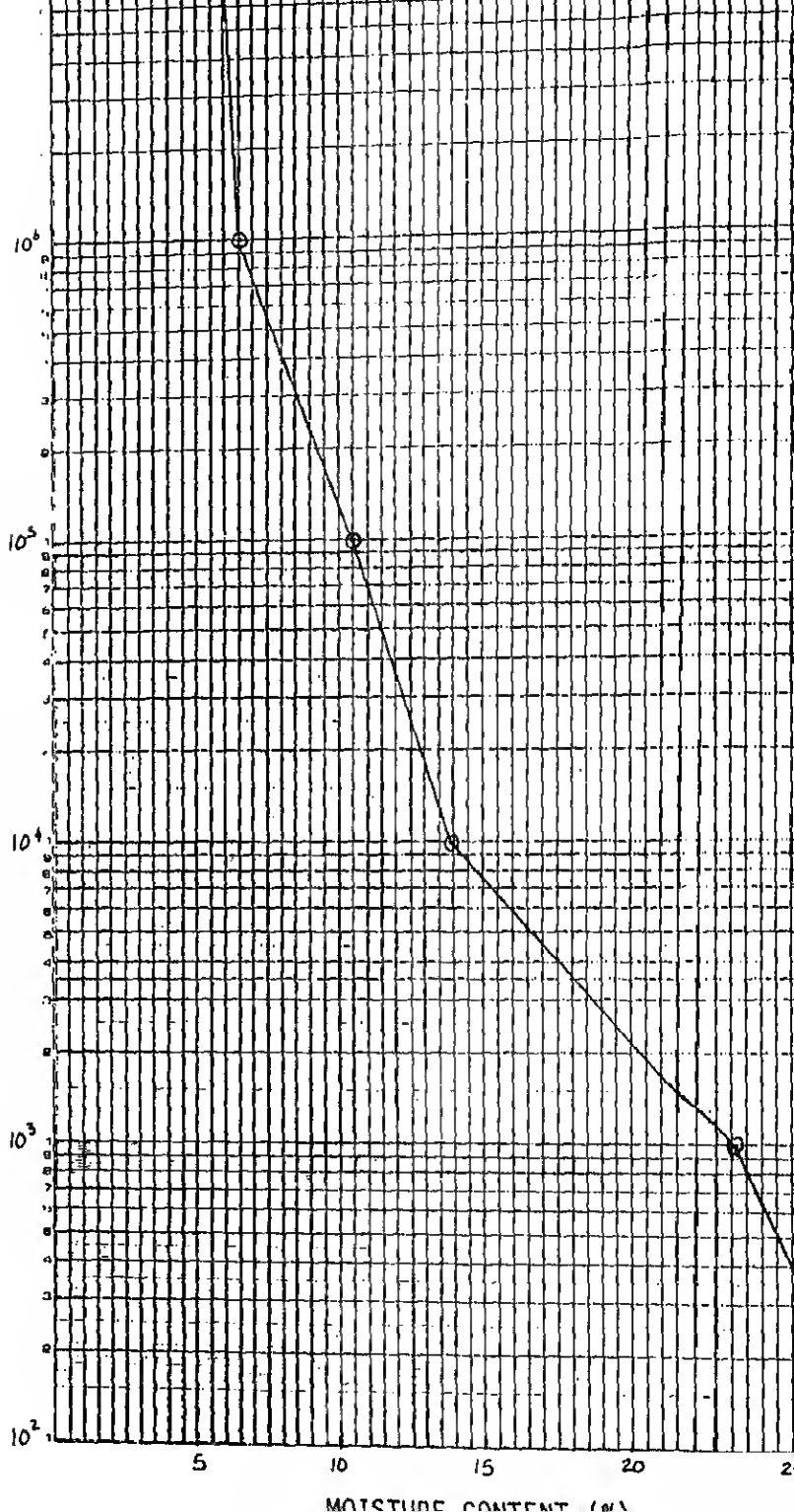
$10^4$

$10^3$

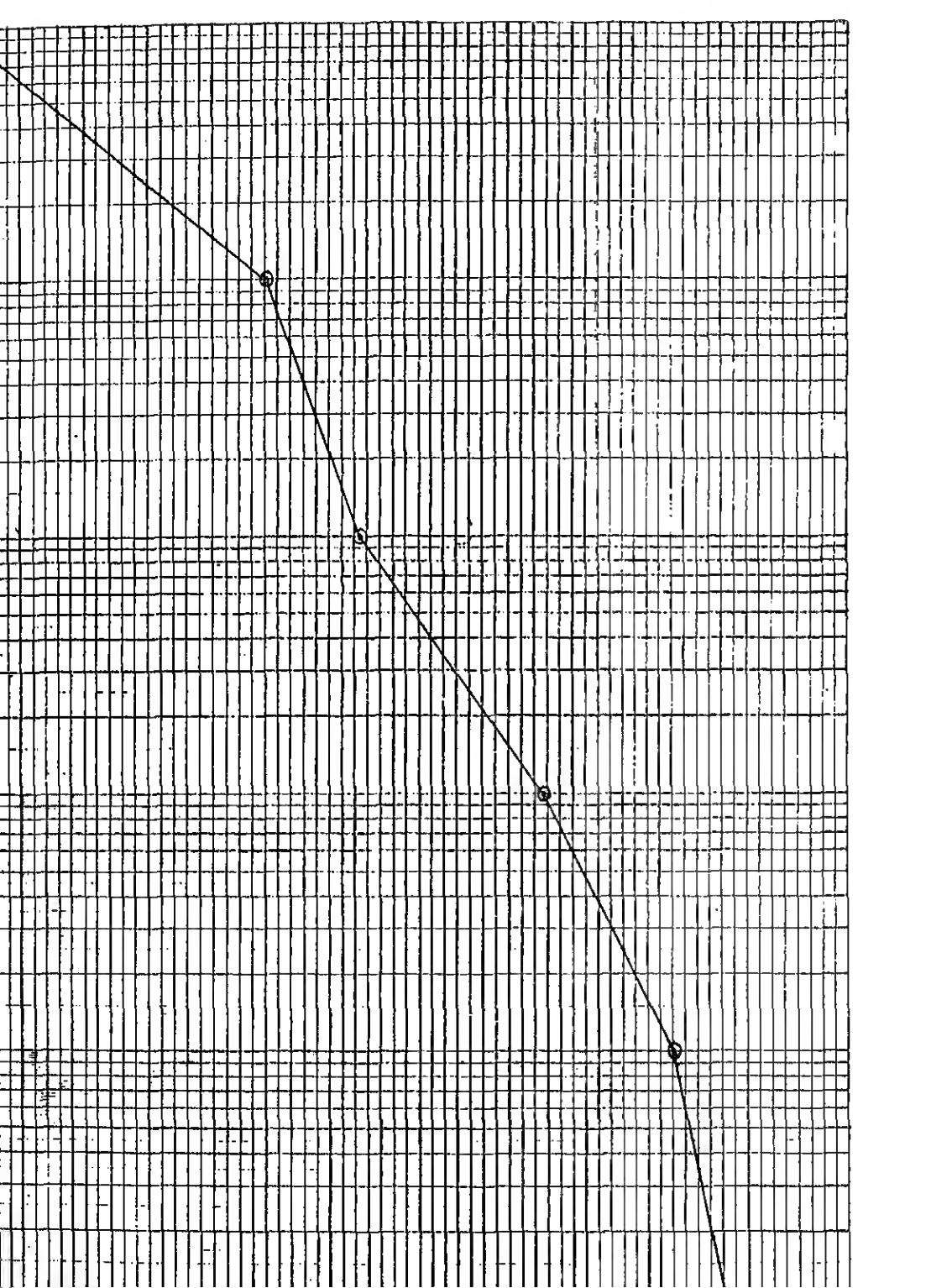




Resistance (Ohms)

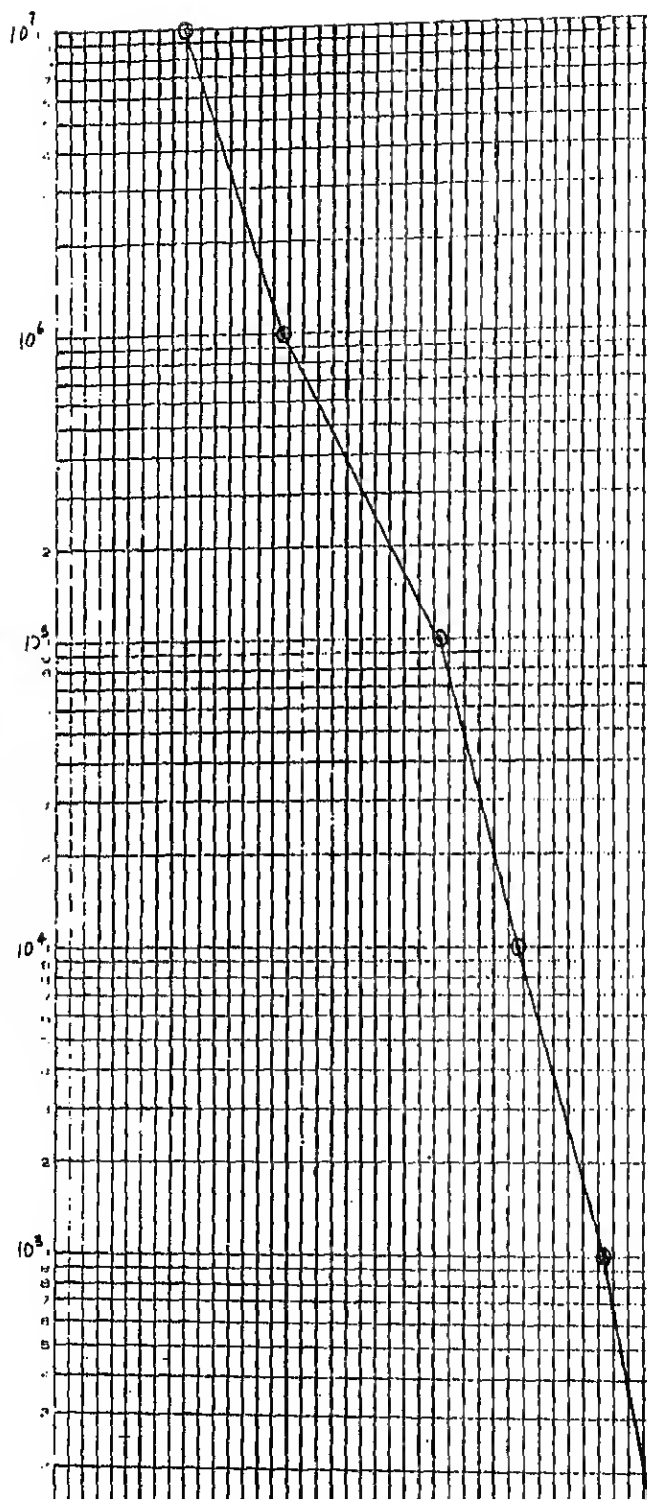


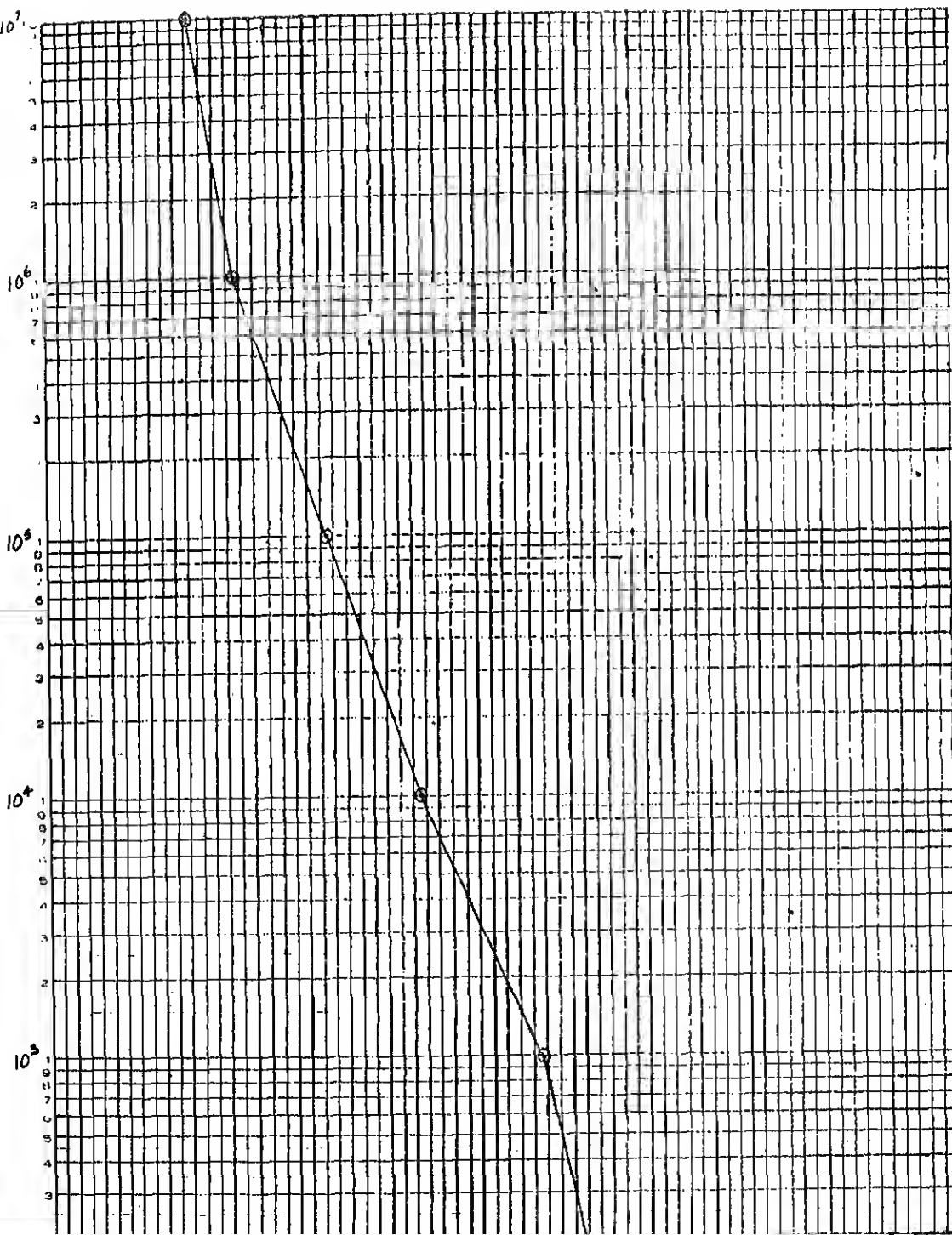
MOISTURE CONTENT (%)

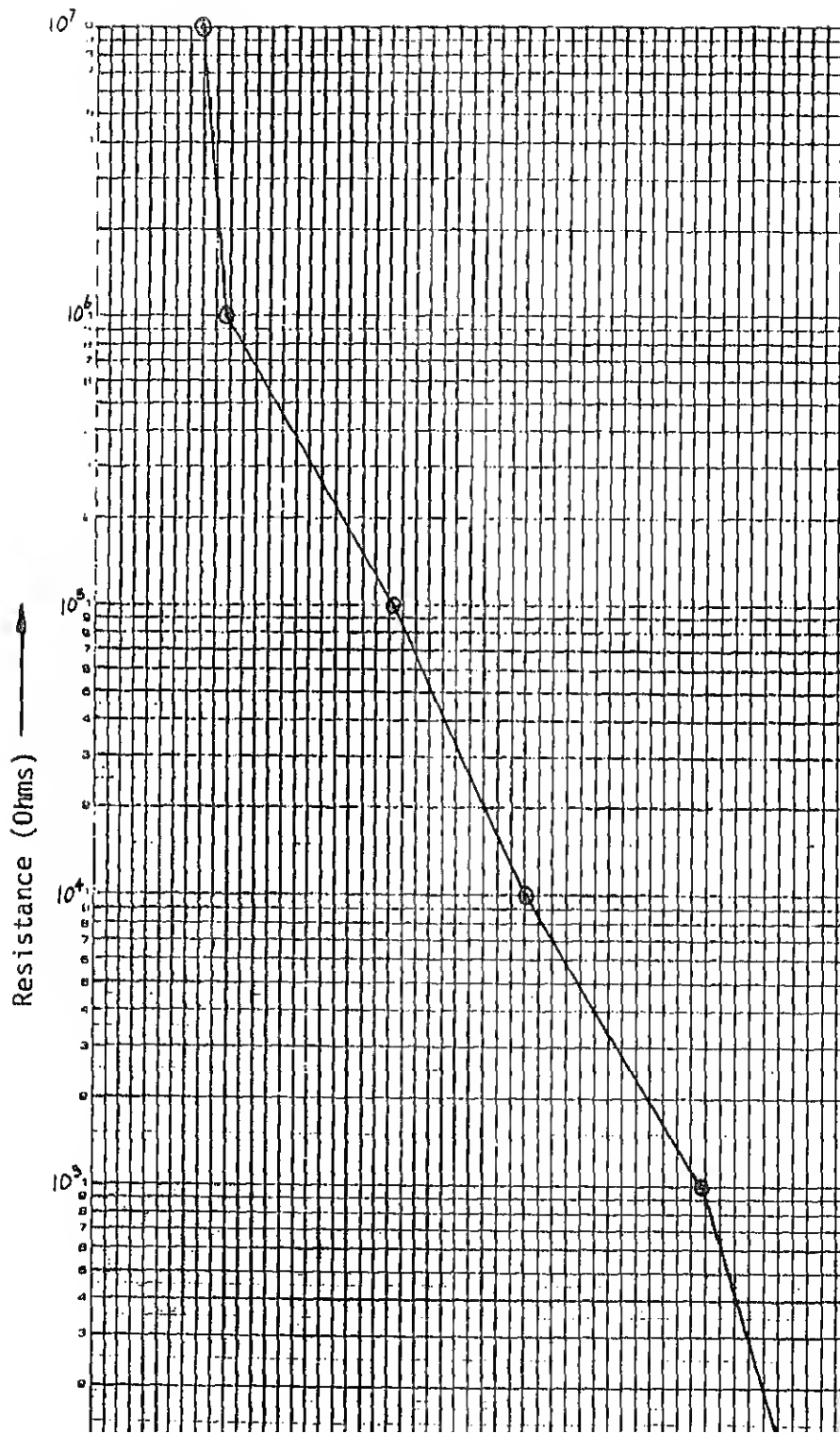


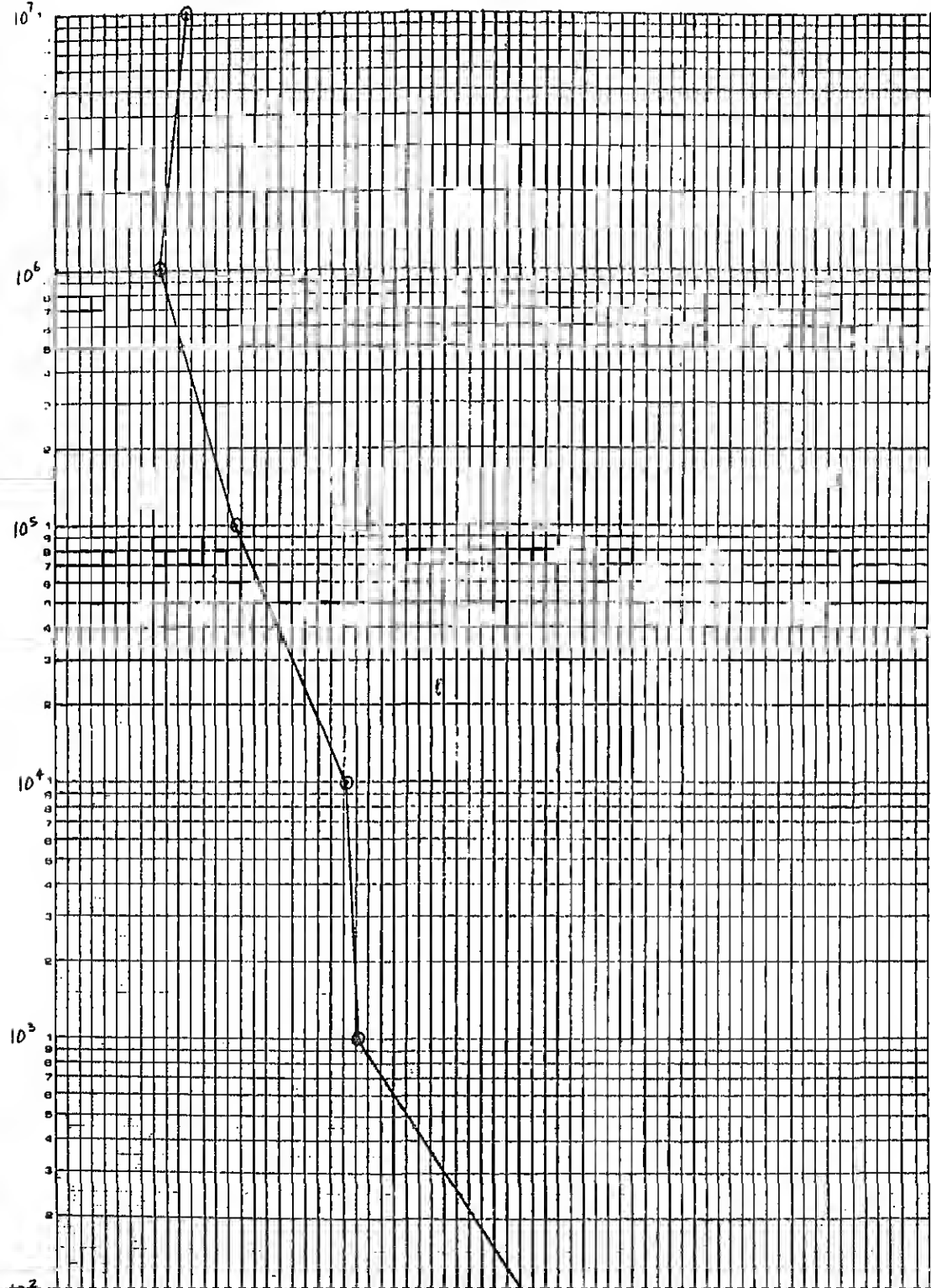


Resistance (Ohms)

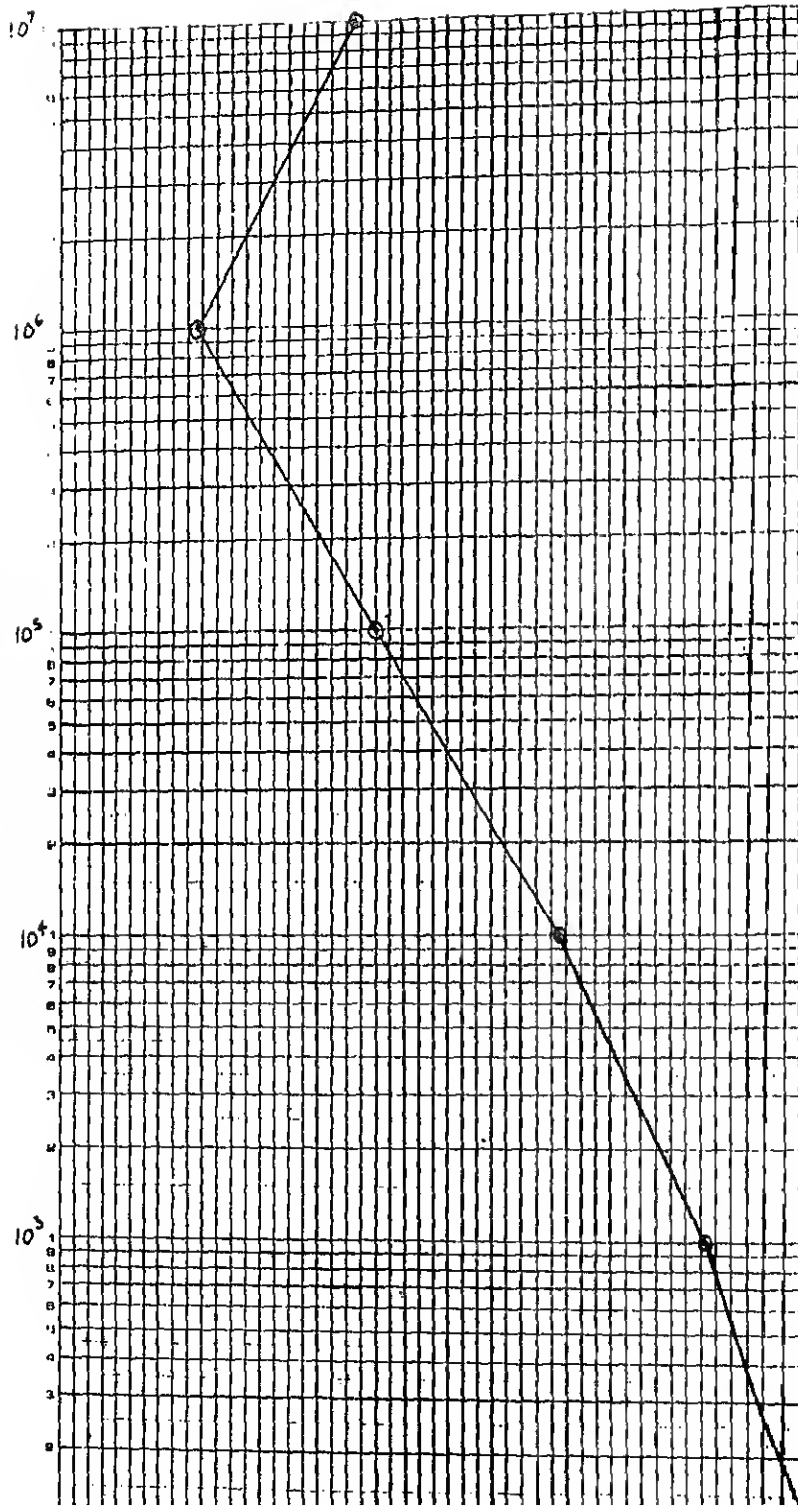








Resistance (Ohms)



### Section 3

## LIME SLURRY INJECTION

### GENERAL

High pressure lime slurry was injected in the soil profile surrounding houses damaged by differential vertical movements. The water-lime slurry mixture was injected into the subgrade adjacent to the perimeter of the foundation to fill fissures and cracks in the subsoil. The injection process increased moisture content of the soil around the critical perimeter area where shrinkage occurred. It has been postulated that the soil immediately adjacent to fissures and cracks filled with slurry would be modified by a reaction between the lime and clay and the shrink-swell behavior will be minimized with time. Further, the lime encompasses clods of soil defined by tension cracks and inhibits volume change.

### HOUSE LOCATIONS

The two houses where subgrade soils were lime injected are representative of those being investigated under Phase I of this project. One is located at 830 N.E. 32nd Street in Grand Prairie, Texas, and is founded on soils of the Pleistocene Ford geologic formation. The other house is located at 2710 Cary Drive in Mesquite, Texas, and is founded on soils belonging to the Taylor Marl geologic formation. Details of the floor plan of each house, injection pattern, instrumentation, leveling points, permanent bench mark, injection procedure, test, soils investigation, and immediate damage reversal have previously been reported (1,2).

### VERTICAL MOVEMENT

During the injection process vertical movement occurred due to the quantity of lime slurry being introduced into the foundation soil at high pressure. Vertical movement was recorded in order to compare the long term vertical movements with the initial movement. This would be indicative of the effectiveness of the stabilization technique. All four surveys of each floor slab were performed after the injection process was completed.

#### 3.1 830 N. E. 32nd Street, Grand Prairie, Texas

The perimeter foundation soil for this house accepted 9,742 gallons of slurry containing 10.5 tons of lime. The cost of high pressure lime slurry injection as a remedial measure per linear foot around the house perimeter was \$1.50.

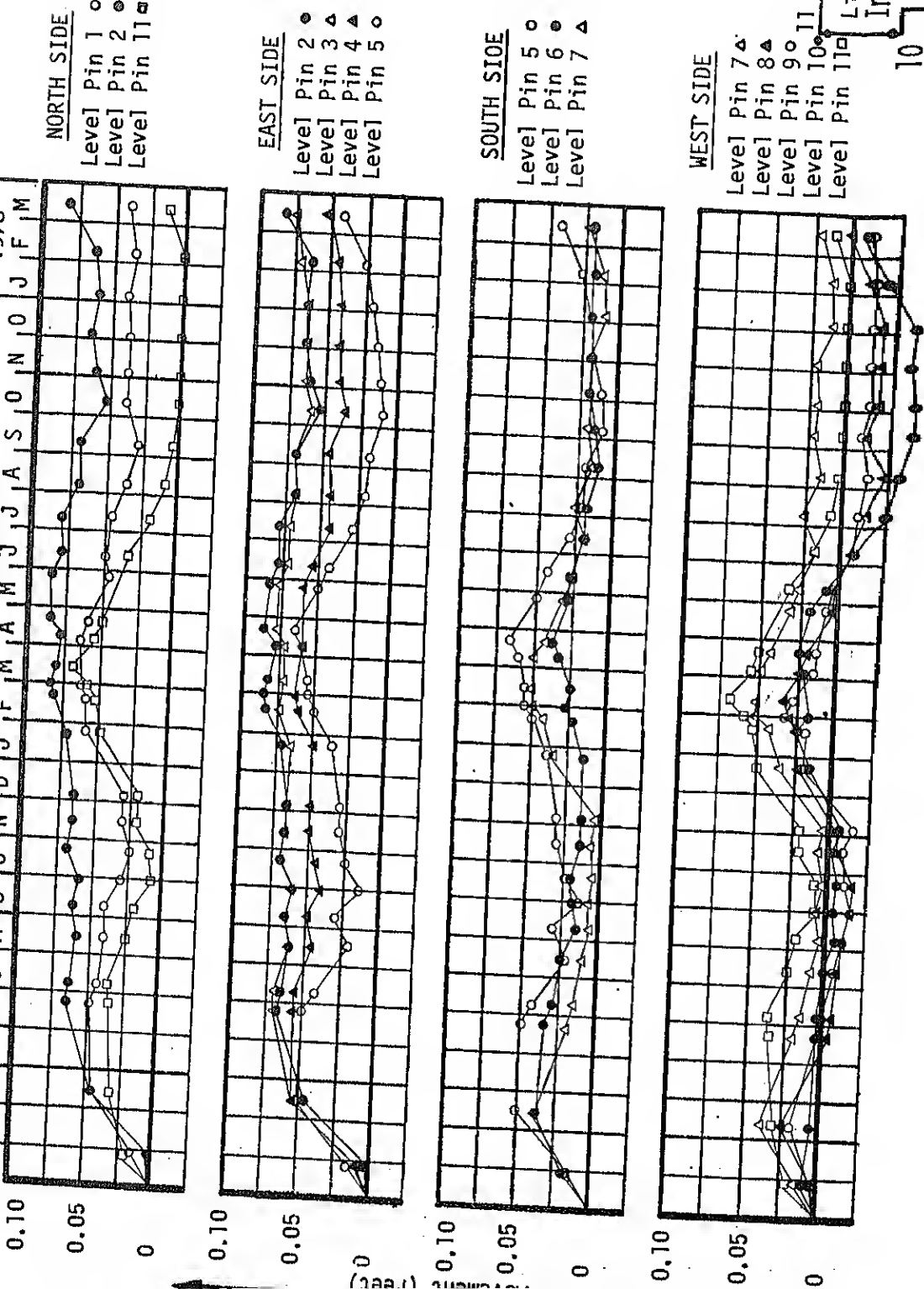


Fig. 11 Vertical m.

An increase in vertical movement occurred as expected due to the development of double layer water on the clay minerals. This increase will continue until equilibrium is reached and then fluctuate with climatic cycle. The vertical movement increase was related to the amount of moisture available, the degree of desiccation of the foundation soil, and the amount of clay minerals in the montmorillonite group present in the soil to the depth of moisture migration.

As indicated by Figure 11, the movement will generally lag behind the completion of the climatic cycle, but can be modified by the effects of trees, soil watering habits or maintenance by the home owner.

Figure 12 indicates the change in elevation or differential movement between corners along each side of the house. Normally, the greatest differential will be between corners as two directions will contribute to movement. This, too, is influenced by the factors previously mentioned and also by variation in soil properties. Information shown in Figure 12 is also given in Table 3.

## 2. 2710 Cary Drive, Mesquite, Texas

The perimeter foundation soil around this house accepted 16,203 gallons of lime slurry containing 20.25 tons of lime. The cost of high pressure lime slurry injection as a remedial stabilization measure around the house perimeter was \$28.27 per lineal foot of the house perimeter.

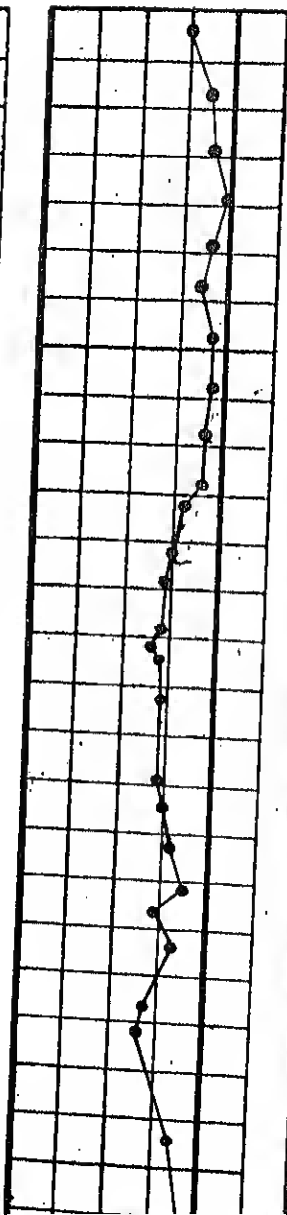
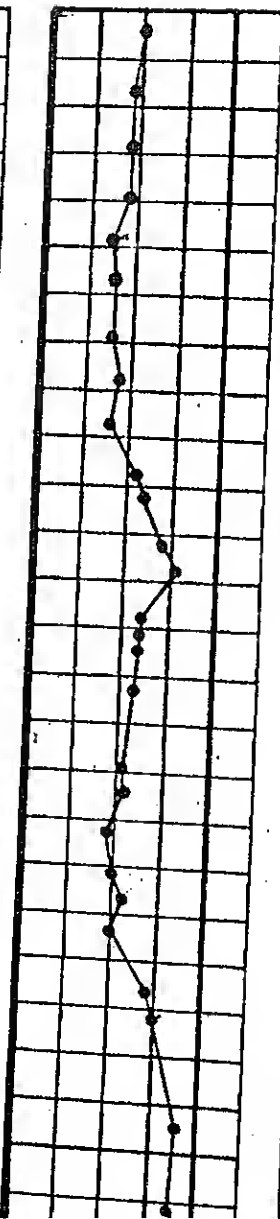
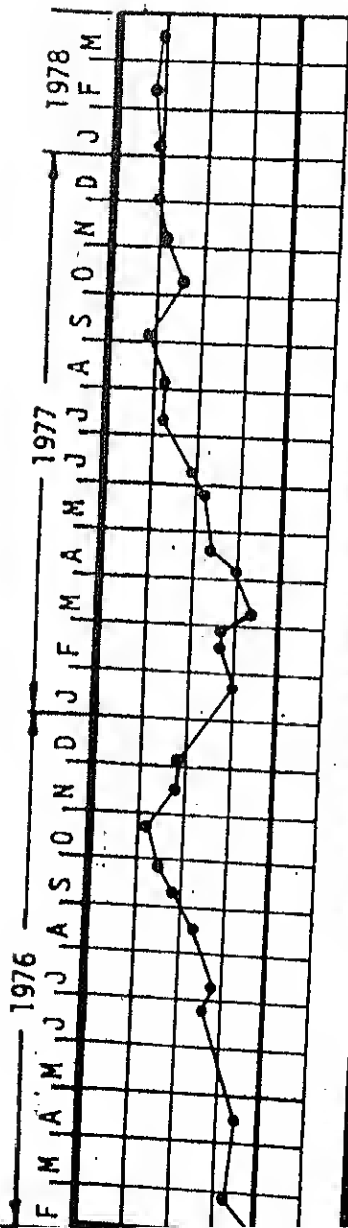
The vertical movement of the foundation slab appears to be approaching a stable condition as indicated in Figure 13, for the same reasons as given in paragraph 3.3.1. Also indicated is the lag time behind the mid point of a climatic cycle. Figure 14 indicates the maximum differential movement with time along sides of the house, and is also given in tabular form in Table 4.

## 3.3 Comparison of Vertical Movement

It was evidenced during this project that the Taylor formation was very dense and contained significant amount of silts and very fine sand. Planes of weakness or desiccation cracks permitted significantly more lime slurry to be injected in the Taylor formation before refusal. The dense condition of the highly expansive soils allowed significant quantities of moisture to be accepted by the active clay minerals to the depth of moisture migration.

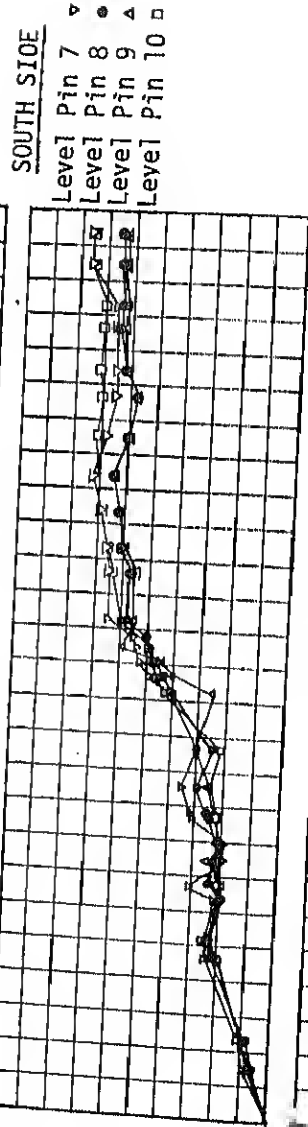
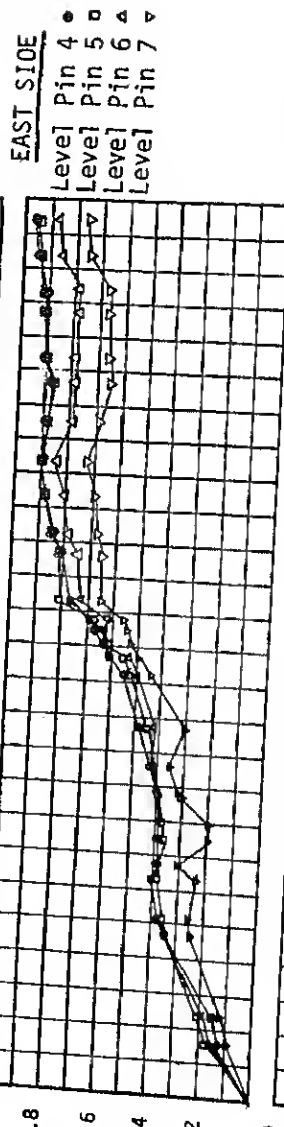
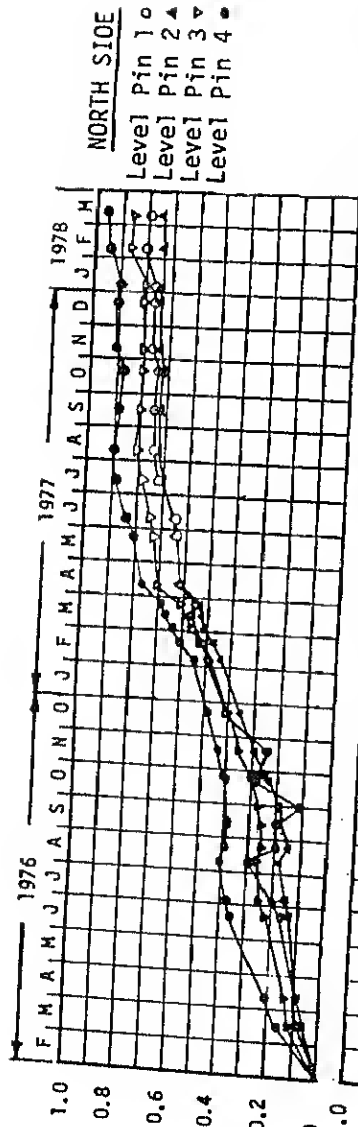
The volume of lime slurry injected into the foundation soils for the house at 2710 Cary Drive, Mesquite, Texas was 1.66 times the volume required for the house at 830 N.E. 32nd Street, Grand Prairie, Texas, or 16,203 gallons and 9,742 gallons respectively. The high pressures associated with this technique (50 psi) will open planes of weakness in a fractured soil such as existed beneath the house at 2710 Cary Drive, Mesquite, Texas.

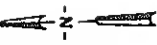
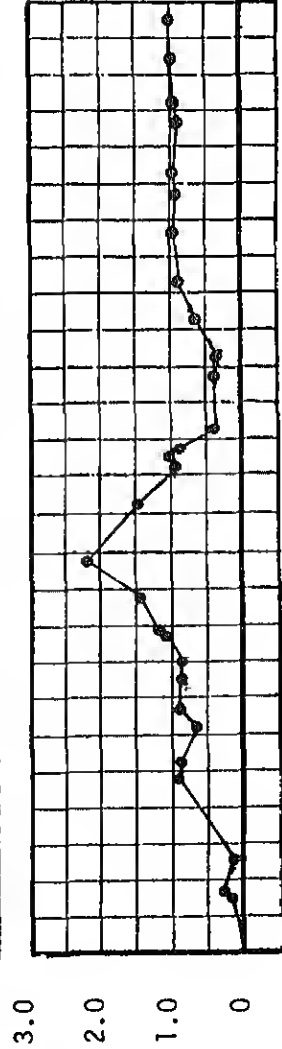
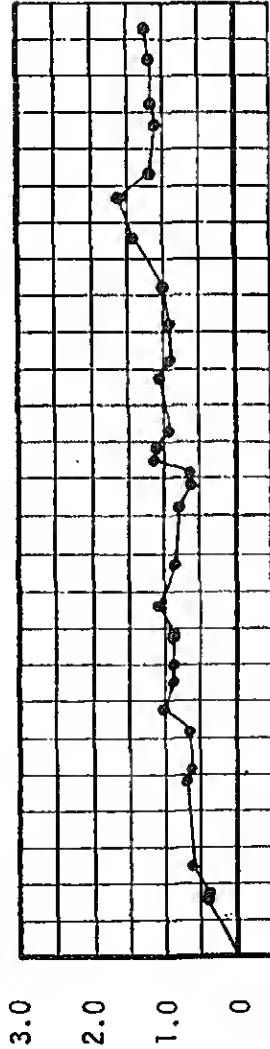
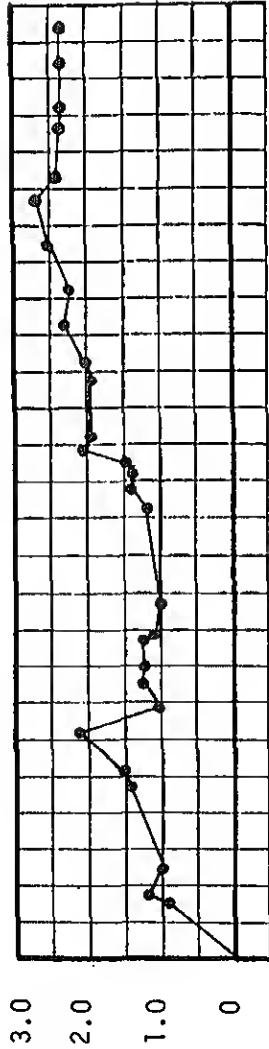
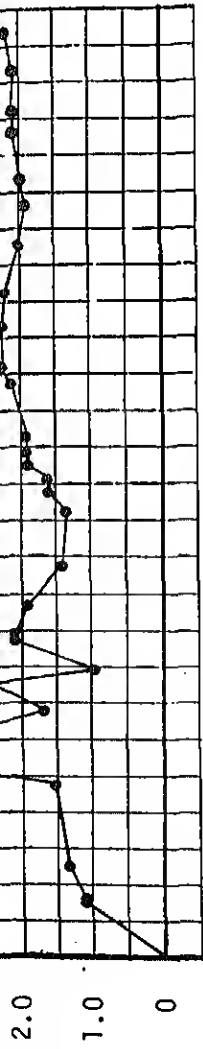




A N I

	North Side			East Side			South Side			West Side		
	Ft.	In.	Cm.	Ft.	In.	Cm.	Ft.	In.	Cm.	Ft.	In.	Cm.
-76	.018	.216	.549	.011	.132	.335	.006	.072	.183	.016	.192	.4
-76	.014	.168	.427	.010	.120	.305	.014	.168	.427	.033	.396	1.0
-76	.030	.360	.914	.021	.252	.640	.030	.360	.914	.039	.468	1.1
-76	.027	.324	.823	.027	.324	.823	.028	.336	.853	.042	.504	1.2
-76	.035	.420	1.067	.042	.504	1.280	.015	.180	.457	.032	.384	.9
-76	.045	.540	1.372	.037	.444	1.128	.023	.276	.701	.029	.348	.8
-76	.053	.636	1.615	.043	.516	1.311	.010	.120	.305	.022	.264	.6
-76	.059	.708	1.798	.046	.552	1.402	.019	.228	.579	.027	.324	.8
-76	.046	.552	1.402	.039	.468	1.189	.021	.252	.640	.029	.348	.8
-76	.046	.552	1.402	.040	.480	1.219	.024	.288	.732	.036	.432	1.0
-77	.023	.276	.701	.036	.432	1.097	.023	.276	.701	.033	.396	1.0
-77	.028	.336	.853	.033	.396	1.006	.027	.324	.823	.034	.408	1.0
-77	.028	.336	.853	.034	.408	1.036	.026	.312	.792	.041	.492	1.2
-77	.014	.158	.427	.028	.336	.853	.029	.348	.884	.038	.456	1.1
-77	.021	.252	.640	.019	.228	.579	.025	.300	.762	.040	.480	1.2
-77	.035	.420	1.067	.024	.288	.732	.026	.312	.792	.040	.480	1.2
-77	.037	.444	1.128	.034	.408	1.036	.022	.264	.671	.040	.480	1.2
-77	.044	.528	1.341	.037	.444	1.128	.016	.192	.488	.032	.384	.9
-77	.059	.708	1.798	.051	.612	1.554	.009	.108	.274	.028	.336	.8
-77	.057	.684	1.737	.048	.576	1.463	.008	.096	.244	.035	.420	1.0
-77	.065	.780	1.981	.051	.612	1.554	.008	.096	.244	.033	.396	1.0
-77	.052	.624	1.585	.051	.612	1.554	.012	.144	.366	.045	.540	1.3
-77	.061	.732	1.859	.053	.636	1.615	.009	.108	.274	.036	.432	1.0
-77	.064	.768	1.951	.047	.564	1.433	.002	.024	.061	.034	.408	1.0
-78	.064	.768	1.951	.045	.540	1.372	.010	.120	.305	.035	.420	1.0
-78	.070	.840	2.134	.045	.540	1.372	.011	.132	.335	.023	.276	.7
-78	.068	.816	2.073	.042	.504	1.280	.020	.240	.610	.035	.420	1.0





East Side

South Side

West Side

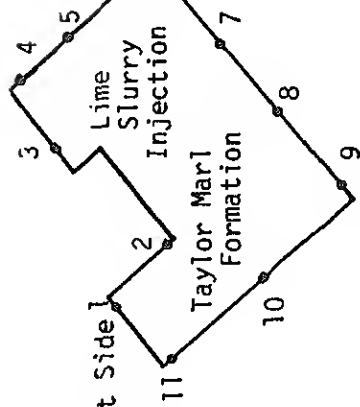


Fig. 14 Differential Elevation on Slab Perimeter

Date	North Side			East Side			South Side		
	Ft.	In.	Cm.	Ft.	In.	Cm.	Ft.	In.	C.
03-16-76	.094	1.128	2.865	.080	.960	2.438	.039	.468	1.
13-18-76	.088	1.056	2.682	.101	1.212	3.078	.037	.444	1.
04-14-76	.115	1.380	3.505	.082	.984	2.499	.046	.552	1.
06-23-76	.126	1.512	3.840	.118	1.416	3.597	.058	.696	1.
07-07-76	.234	2.808	7.132	.126	1.512	3.840	.047	.564	1.
08-11-76	.233	2.796	7.102	.177	2.124	5.395	.052	.624	1.
08-24-76	.133	1.596	4.054	.091	1.092	2.774	.084	1.008	2.
09-15-76	.205	2.460	6.248	.106	1.272	3.231	.070	.840	2.
09-30-76	.081	.972	2.469	.099	1.188	3.018	.070	.840	2.
10-22-76	.179	2.148	5.456	.106	1.272	3.231	.072	.864	2.
10-26-76	.178	2.136	5.425	.094	1.128	2.865	.074	.888	2.
11-18-76	.157	1.884	4.785	.088	1.056	2.682	.091	1.092	2.
12-21-76	.122	1.464	3.719	.184	xx	5.608	.070	.840	2.
02-07-77	.111	1.332	3.383	.104	1.248	3.170	.067	.804	2.
02-21-77	.134	1.608	4.084	.116	1.392	3.536	.044	.528	1.
03-03-77	.135	1.620	4.115	.111	1.332	3.383	.063	.756	1.
03-14-77	.156	1.872	4.755	.131	1.572	3.993	.104	1.248	3.
03-25-76	.166	1.992	5.060	.177	2.124	5.395	.193	1.116	2.
04-11-77	.164	1.968	4.999	.177	2.124	5.395	.083	.996	2.
05-23-77	.182	2.184	5.547	.166	1.992	5.060	.089	1.068	2.
06-09-77	.189	2.268	5.761	.171	2.052	5.212	.079	.948	2.
07-12-77	.183	2.196	5.578	.194	2.328	5.913	.079	.948	2.
08-11-77	.185	2.220	5.639	.187	2.244	5.700	.088	1.050	2.
09-15-77	.168	2.016	5.121	.210	2.500	6.401	.120	1.440	3.
10-21-77	.162	1.944	4.938	.227	2.724	6.919	.129	1.548	3.
11-11-77	.166	1.992	5.060	.206	2.472	6.279	.103	1.236	3.
12-20-77	.177	2.124	5.395	.198	2.376	6.035	.093	1.116	2.
01-05-78	.173	2.100	5.334	.198	2.376	6.035	.098	1.176	2.
02-13-78	.176	2.112	5.364	.199	2.388	6.066	.099	1.188	3.
03-10-78	.184	2.208	5.608	.201	2.412	6.126	.102	1.224	3.

A comparison of Figure 11 and 13, pages 22 and 26, indicates the magnitude of vertical movement associated with this stabilization technique. A maximum vertical movement of approximately 11 inches has occurred for the house at 2100 E. Drive, Mesquite, Texas, and a maximum vertical movement approximating 6 inches occurred some 10 months earlier at the test house at 830 N.E. 32nd Street and Prairie, Texas.

It was also seen from the vertical movements given in Figure 11 page 25, that climatic effects were having an influence on the stability of the foundations. These movements appeared to be dampening out with time, however, the condition that exists would defeat the objective of the stabilization program. Climatic effects are not as apparent in Figure 13, page 29, however, this was attributed to the scale of the figure. It can be seen from Figure 14, page 31, the magnitude of differential movements occurring over a short period of time is very undesirable.

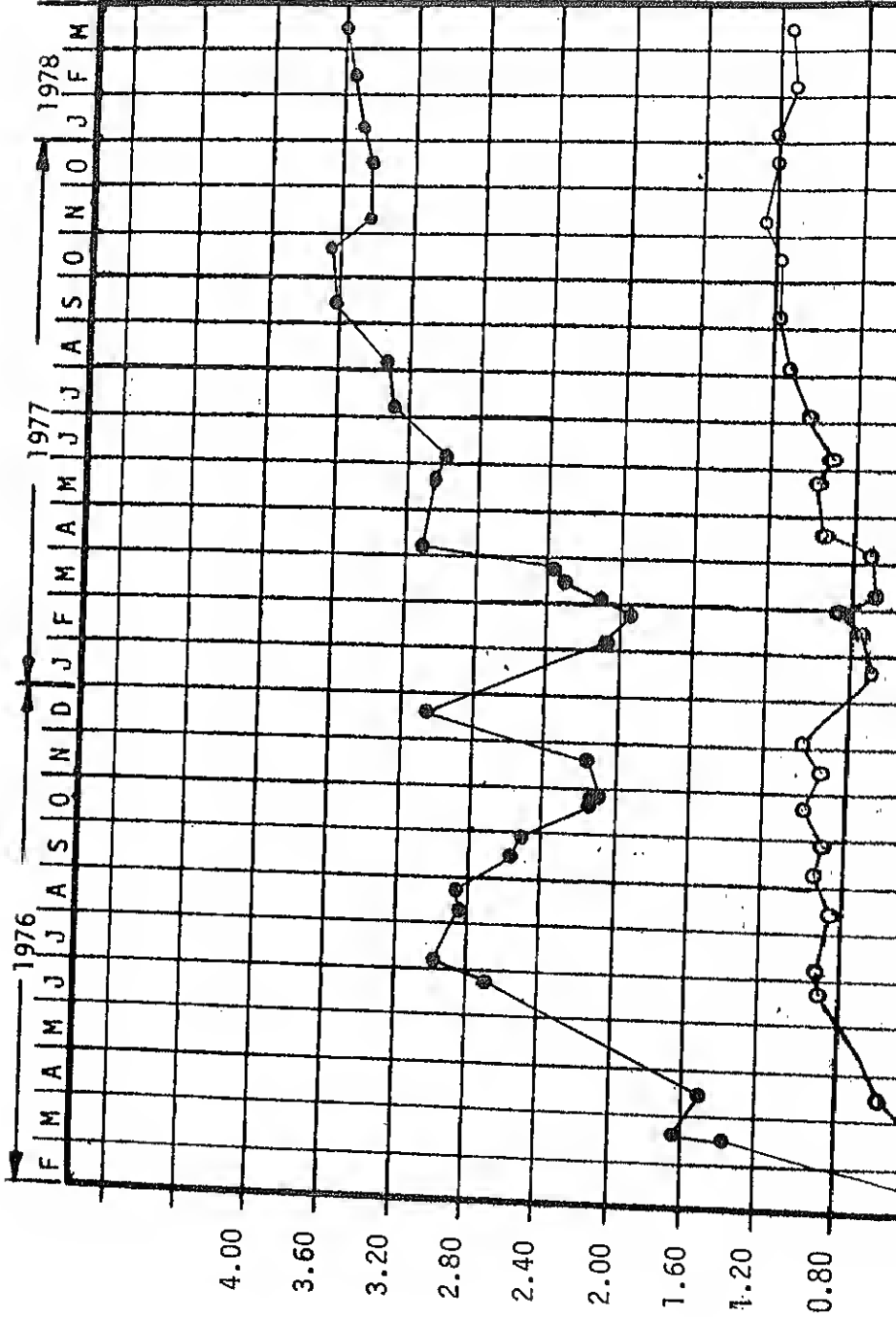
Figure 15, and Tables 5 and 6, show a comparison of lime slurry pressure injection as a soil stabilization technique. Values shown are absolute values and give an indication of technique effectiveness as well as activity of each foundation for the period of time of this study. As each curve becomes asymptotic to a horizontal plane, a condition of stability was considered approaching. It can be seen the differential movements associated with a stability condition could be considered acceptable.

### SOIL-MOISTURE-TEMPERATURE CHARACTERISTICS

The placement of moisture-temperature cells at specified depths in the foundation soil have previously been discussed<sup>(1,2)</sup>. It is reiterated, that the spacing for each instrument string could not be placed closer to the perimeter of the beam than one foot due to equipment limitations. Consequently, stabilization actions were approximately 18-24 inches outside the perimeter beam. The horizontal area completely around the perimeter of the house was subjected to climatic conditions to some degree.

Moisture data is presented by plotting it at the same depths on all four sides of the test houses. Thus, there will be four curves at each depth within the foundation soil (except for the houses where lime slurry pressure injection was studied as a stabilization technique). Here five curves are presented with the fifth curve indicating comparative moisture contents of the soil at equivalent depths for instruments established in a soil boring outside the injected area.

Temperature data was analyzed in two ways: (1) temperature vs. time, and (2) average temperature for parallel sides vs. time. Cyclic variation is depicted in the plots of temperature vs. time. These plots have been developed for the design of instrument installation. Temperature data is averaged for the borings along all parallel sides of the structure. For each house and each depth, two curves are plotted (these curves represent the average temperature for the borings on opposite sides of the structure).



Date	Movement		
	Feet	Inches	Cm.
Feb. 27, 1976	.018	.216	.549
Apr. 14, 1976	.049	.588	1.494
June 23, 1976	.073	.876	2.225
July 9, 1976	.074	.888	2.256
Aug. 16, 1976	.069	.828	2.103
Sep. 9, 1976	.076	.912	2.316
Sep. 29, 1976	.075	.900	2.286
Oct. 21, 1976	.086	1.032	2.621
Nov. 16, 1976	.075	.900	2.286
Dec. 2, 1976	.084	1.008	2.560
Jan. 21, 1977	.059	.708	1.798
Feb. 18, 1977	.062	.744	1.890
Feb. 28, 1977	.069	.828	2.103
Mar. 11, 1977	.057	.684	1.737
Apr. 4, 1977	.061	.732	1.859
Apr. 19, 1977	.075	.900	2.286
May 24, 1977	.080	.960	2.438
June 10, 1977	.076	.912	2.316
July 8, 1977	.087	1.044	2.652
Aug. 5, 1977	.094	1.128	2.865
Sep. 8, 1977	.099	1.188	3.018
Oct. 10, 1977	.095	1.140	2.896
Nov. 4, 1977	.102	1.224	3.109
Dec. 1, 1977	.098	1.176	2.987
Jan. 4, 1978	.100	1.200	3.048
Feb. 6, 1978	.093	1.116	2.835
Mar. 17, 1978	.095	1.140	2.896



Date	Movement		
	Feet	Inches	Cm.
Mar. 16, 1976	.119	1.428	3.627
Mar. 18, 1976	.138	1.656	4.206
Apr. 14, 1976	.128	1.536	3.901
June 23, 1976	.226	2.712	6.888
July 7, 1976	.244	2.928	7.437
Aug. 11, 1976	.235	2.820	7.163
Aug. 24, 1976	.236	2.832	7.193
Sep. 15, 1976	.215	2.580	6.553
Sep. 30, 1976	.204	2.448	6.218
Oct. 22, 1976	.179	2.148	5.456
Oct. 26, 1976	.178	2.136	5.425
Nov. 18, 1976	.179	2.148	5.456
Dec. 21, 1976	.254	3.048	7.742
Feb. 7, 1977	.171	2.052	5.212
Feb. 21, 1977	.160	1.920	4.877
Mar. 3, 1977	.174	2.088	5.304
Mar. 14, 1977	.192	2.304	5.852
Mar. 25, 1977	.198	2.376	6.035
Apr. 11, 1977	.260	3.120	7.925
May 23, 1977	.255	3.060	7.772
June 9, 1977	.250	3.000	7.620
July 12, 1977	.273	3.276	8.321
Aug. 11, 1977	.275	3.300	8.382
Sep. 15, 1977	.301	3.612	9.174
Oct. 21, 1977	.302	3.624	9.205
Nov. 11, 1977	.287	3.444	8.748
Dec. 20, 1977	.391	3.492	8.870
Jan. 5, 1978	.293	3.516	8.931
Feb. 13, 1978	.298	3.576	9.096

Averaging of temperature data was done to yield a less cumbersome graph. However, it obscures the individual temperature variations that are present. To show these, calculations of means and standard deviations of temperature are presented in tables for each boring and at each depth. The standard deviation indicates the amount of variation contained in the data. A small standard deviation indicates data which is clustered around the mean value, and a large standard deviation indicates data which has large fluctuations above and below the mean. The standard deviations indicate the relative amounts of variation with time. These tables indicate the temperature is not uniform around the perimeter.

1 830 N.E. 32nd Street, Grand Prairie, Texas

Data acquisition for variation in soil moisture content with time, as shown in Figure 16, began upon completion of the high pressure lime slurry pressure stabilization process. It is readily apparent that the soil moisture content immediately after the injection process, and with time, has a wide variation. This variation is indicative of the slurry migrating away from the desired area of treatment. If the stabilization technique was effective, the soil moisture contents at depths of interest should fall within a very narrow band width and remain relatively horizontal with time. It can be seen that climatic conditions are influencing the soil moisture content at all depths of interest. In addition, transpiration systems from trees and other vegetation would contribute to an apparent climatic effect at near surface elevations. The curve indicating soil moisture content at all depths of interest outside of the treatment area is not significantly different than the four curves within the treatment area. This is an indication that moisture migration has not been appreciably inhibited and was fluctuating with climatic conditions.

The variation of the soil temperature as given in Figure 17 shows the characteristic sine wave with changes associated with climate. Temperature data should not have any or significant lag time as would be the case for moisture. At the depths of interest, the amplitude of the characteristic wave decreases with the depth of soil cover. The temperature means and standard deviations are given in Table 7.

Increasing the soil moisture content to a value of 2-3 percent above the Plastic Limit, which is desirable, was not successful utilizing this stabilization technique. It can be seen that for each depth of interest, the moisture content should have approached and maintained a value of approximately 24-25 percent for an average Plastic Limit of approximately 22 percent. Instead the moisture content never exceeded 20 percent and fluctuated widely with the season.

2 2710 Cary Drive, Mesquite, Texas

appropriate for this test house.

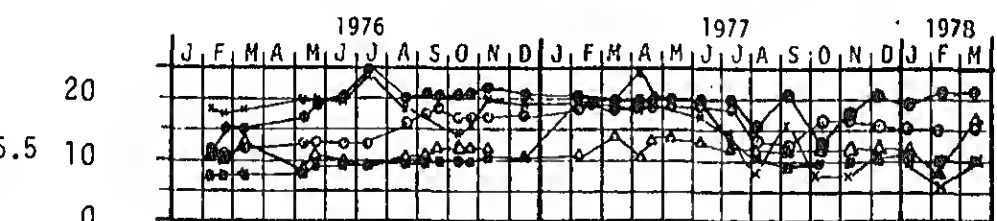
The average Plastic Limit within the depths of interest was 36%. This would establish a desirable soil moisture content of 38%. As can be seen, initially, moisture contents approached this value but could not be maintained by this stabilization technique.

The variation of the soil temperature with time and depth is shown in Figure 19. This figure illustrates the characteristic sine wave pattern. The amplitude decreases with depth. Temperature means and standard deviations are given in Table 8, page 37.

### 3.4.3 Comparison of Moisture-Temperature Characteristics

The variation of soil moisture content with time for these two different geologic formations is as dramatic as the variation in vertical movements. From the soils investigation for these two houses, the soil properties such as natural water content, Plastic Limit, and Liquid Limit were significantly higher in the Taylor formation, or the house located at 1000 West Drive, Mesquite, Texas. Further, the natural water content of the soil at 7 foot depth for the Taylor formation was significantly lower than the Plastic Limit of the soil. Within depths of interest in this investigation, the maximum amount of soil moisture variation was as much as 11% below the Plastic Limit in the Taylor formation, whereas in the Eagle Ford formation 5% below the Plastic Limit appeared to be maximum. In addition, the percentage of montmorillonite clay minerals determined by x-ray Diffraction Analysis was much greater in the Taylor formation than in the Eagle Ford formation. For depths of interest at the soil surface, the increase (in what) was as much as 45 percent at the 1000 West elevations and 20 percent at the 7 foot depth. The lime slurry was laterally inserted to this depth; however, the extent of the moisture migration vertically and laterally along fissures and planes of weakness was unknown, and it would be a function of the degree of desiccation and past geologic history. However, it is believed that moisture migration was wide spread for pressures of 150 psi, and both, the vertical movements and moisture migration support this premise.

The high specific surface area of montmorillonite clay minerals (100 square meters per gram), along with the large volume of water introduced into the profile of the house located on the Taylor formation versus the house on the Eagle Ford formation indicates the subsoil under the house at 1000 West Drive, Mesquite, Texas, was capable of retaining more moisture. Referenced on page 30, which compares the maximum perimeter differential movements for the house where the subsoil was treated by lime slurry pressure injection. This figure indicates the significant difference in activity of the subsoil for the houses on the Taylor and Eagle Ford formations. Similar indications are given by comparing Figures 11 and 13, pages 22 and 26, which show

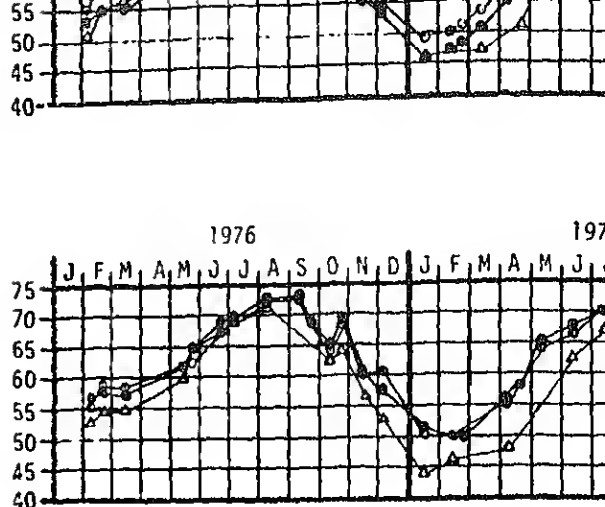


- North Side Boring
- East Side Boring
- △ South Side Boring
- West Side Boring
- x Instruments Outside of Lime Treatment Area
- \* Refers to Depth Below Perimeter Grade Beam

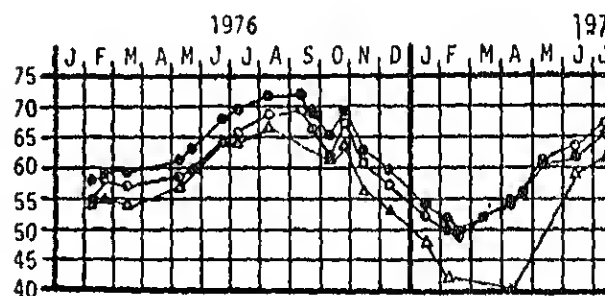
Fig. 16 Soil Moisture Content - Lime Slurry Injection  
830 N.E. 32nd Street, Grand Prairie, Texas

Soil Temperature ( $^{\circ}\text{F}$ )

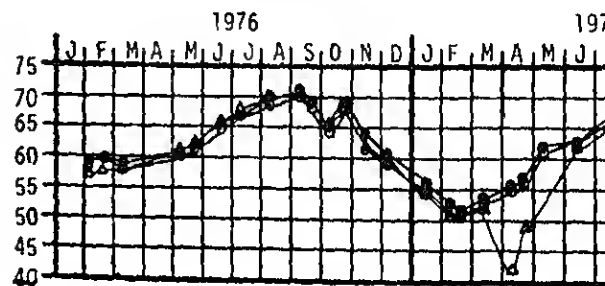
Depth 2.5



Depth 4



Depth 5.5



-Key-

- North and South Side Average
- East and West Side Average
- △ Instrument Outside of Lime

# URE MEANS AND STANDARD DEVIATION

32nd Street, Grand Prairie, TX

## Lime Injection

	*Depth (ft)			
	1	2.5	4	5.5
	62.00 9.58	61.82 7.54	58.98 6.92	60.45 6.40
	58.58 8.70	61.47 8.00	60.28 7.50	61.93 6.24
	63.89 7.59	63.11 6.10	61.45 5.45	60.97 5.08
	63.47 9.14	64.55 6.83	63.48 5.90	61.71 5.13
	59.68 12.38	58.63 8.43	56.63 7.84	59.28 7.53

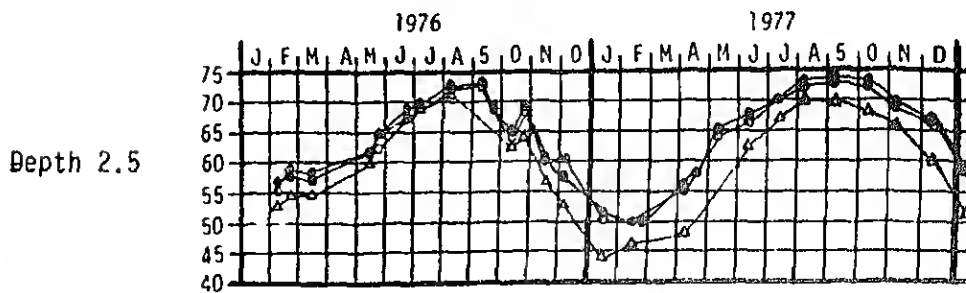
both refers to feet below grade beam.

# TEMPERATURE MEANS AND STANDARD DEVIATION

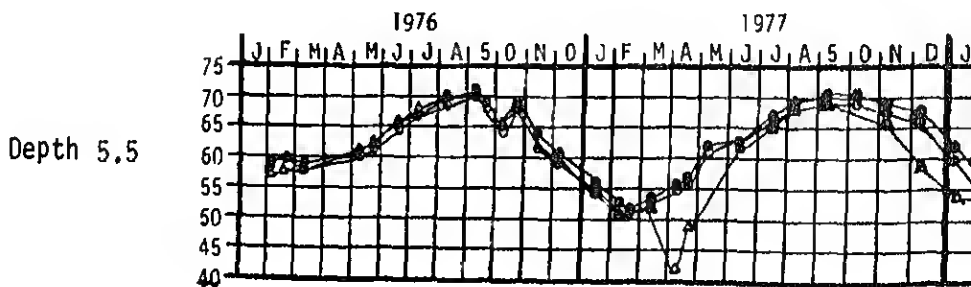
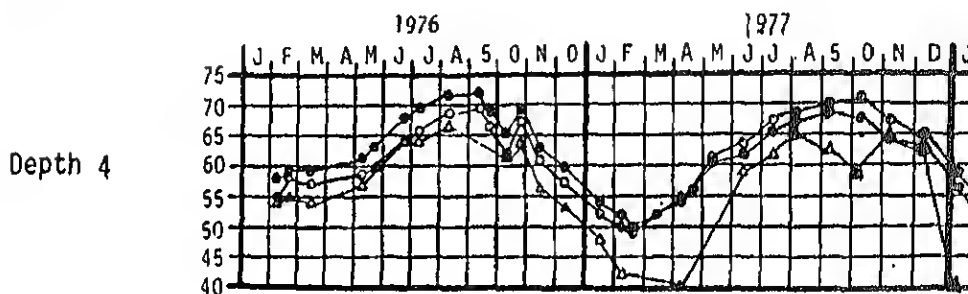
2710 Cary Drive, Mesquite, TX

## Lime Injection

Cell Location	*Depth (ft)			
	1	2.5	4	
North	63.92 9.80	61.61 8.94	60.18 7.71	
East	63.93 8.73	61.05 7.42	62.30 6.22	
South	64.95 7.62	61.83 5.55	61.32 6.01	
West	62.93 5.17	61.55 6.90	60.77 6.09	
Outside Treatment Area	63.94 7.38	61.64 6.85	56.70 5.82	



Soil Temperature ( $^{\circ}\text{F}$ )



-Key-

- North and South Side Average
- East and West Side Average
- △ Instrument Outside of Lime Treatment Area

\*Depths refer to feet below grade beam.

## Lime Injection

Cell Location	*Depth (ft)		4	5.5
	1	2.5		
North	62.00 9.58	61.82 7.54	58.98 6.92	60.45 6.40
East	58.58 8.70	61.47 8.00	60.28 7.50	61.93 6.24
South	63.89 7.59	63.11 6.10	61.45 5.45	60.97 5.08
West	63.47 9.14	64.55 6.83	63.48 5.90	61.71 5.13
Outside Treatment Area	59.68 12.38	58.63 8.43	56.63 7.84	59.28 7.53

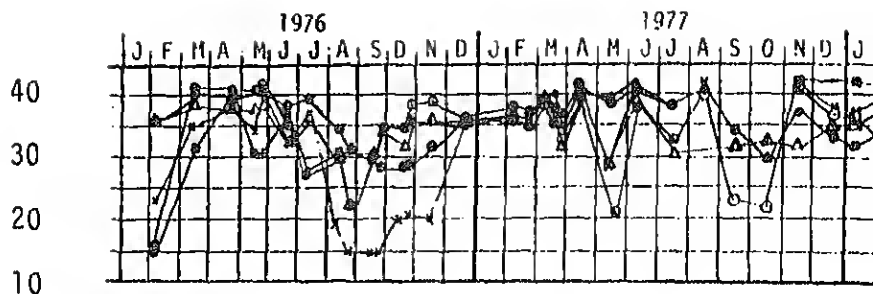
## Lime Injection

Cell Location	*Depth (ft)		2.5	4
	1			
North	63.92 9.80	61.61 8.94	60.1 7.7	62.3 6.2
East	63.93 8.73	61.05 7.42	62.3 6.2	62.3 6.2
South	64.95 7.62	61.83 5.55	61.3 6.0	61.3 6.0
West	62.93 5.17	61.55 6.90	60.7 6.0	60.7 6.0
Outside Treatment Area	63.94 7.38	61.64 6.85	56.7 5.8	56.7 5.8

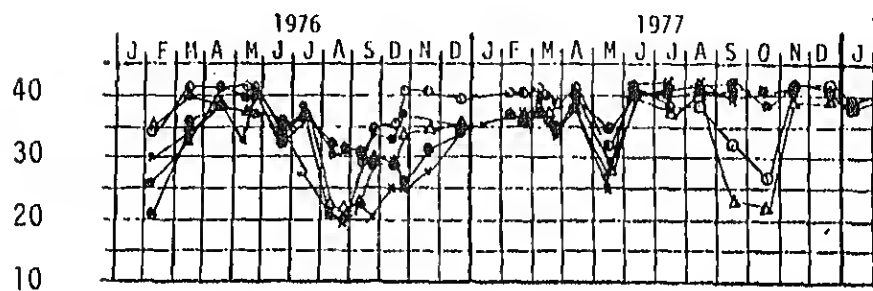
\*Depth refers to feet below grade beam.



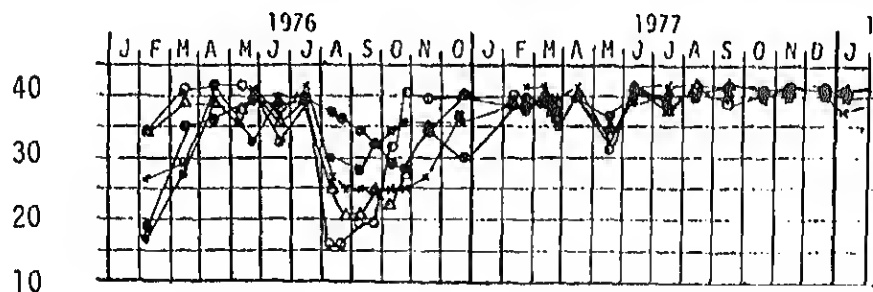
\* Depth 1



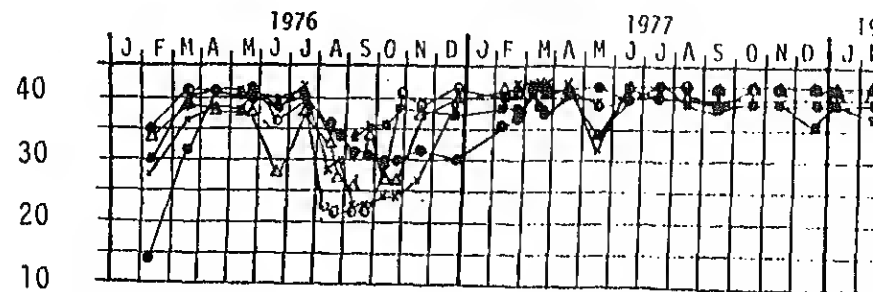
Depth 2.5



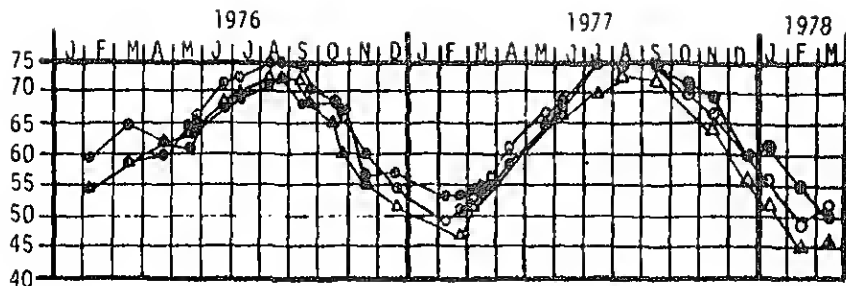
Depth 4



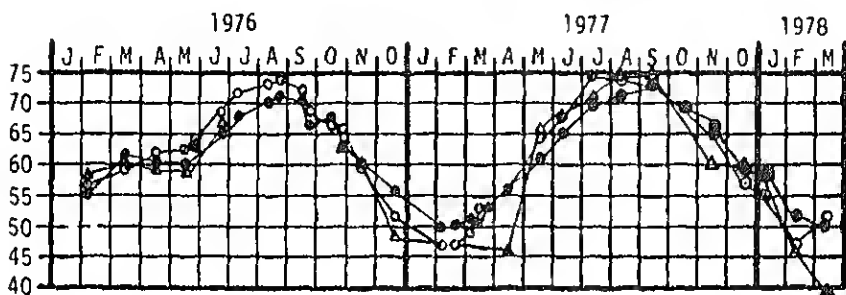
Depth 5.5



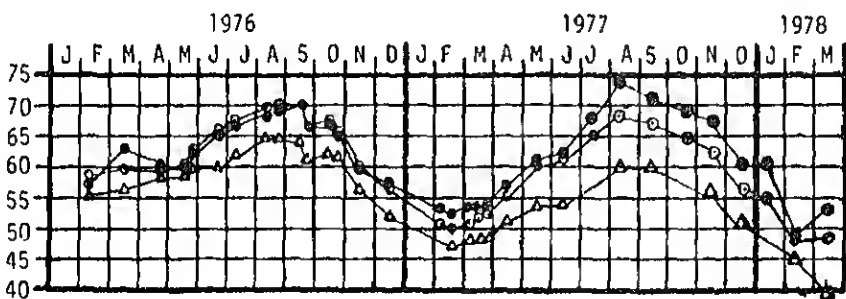
h 1



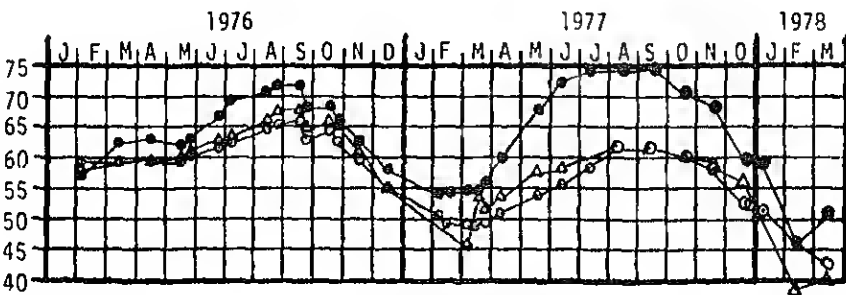
h 2.5



h 4



h 5.5



as, appeared to be approaching a stable condition within several months, the foundation soils beneath the house at 2710 Cary Drive, Mesquite, Texas, continued to swell appreciably for over 18 months. This condition may continue at a reduced rate until the clay minerals have satisfied their double layer water requirement for equilibrium.

The comparison of Figures 17 and 19, pages 36 and 39, for soil temperature variation indicate excellent agreement. Consequently, it would appear that variation of soil temperature with depth is essentially a function of climate variation, and not a significant variable for magnitudes of vertical movement sustained. Both referenced figures give an indication of the insulating properties of soil. This is further justified by the values of temperature means and standard deviations with depth for both houses given in Tables 7 and 8, respectively. The correlation of temperature data is excellent and supports the accuracy of other data values.

## 5 EVALUATION OF LIME SLURRY PRESSURE INJECTION FOR STABILIZATION

The use of lime to inhibit shrink and swell in clay has long been established and used with excellent results. This has usually been in major construction where intimate blending of lime slurry and clay can be achieved and the optimum water content of the mixture maintained. Excellent results have been obtained using the injection process in stabilizing railroad sub-grade that have been restored to desirable configurations. The injection process has also been used successfully in stabilizing large areas of soil to a 7 foot depth, with the surface soil being blended with the returned slurry and compacted to an optimum density. In all these instances, sufficient space is usually available to accommodate large construction equipment required to achieve desired results. Consequently, long term modifications to clays may occur and shrink-swell characteristics will be altered.

The use of established lime slurry injection procedures to stabilize the foundation soils around house perimeters to preclude excessive differential movements would appear to have some limitations. The cost associated with a stabilization technique is of significant interest to the home owner, and usually lime slurry pressure injection is the most costly of all methods used in the study. A considerable investment in specialized equipment is required for lime slurry pressure injection and this necessitates the use of a contractor who specializes in this type of work. Essentially, the same type of equipment is required for injecting around a house perimeter as would be required along either a railroad right of way or a large expanse of soil such as a parking area of an apartment complex. While equipment type may be the same, more special attention is required for the subsoil around a house perimeter.

The cost of lime slurry pressure injection is a function of the size of the area to be treated and the amount of time required to accomplish the job. For a distressed house, space limitations due to lot size and adjacent buildings

the foundation soil by a vibrating device at the top. It is extremely difficult to maintain the alignment of the lance in the soil with vibrating equipment at the top plus a hose connection to the slurry pump which is injected at approximately 150 psi. Consequently, the injection hole tends to become enlarged permitting return of the slurry up around the lance, and this may occur not be before an adequate amount of lime slurry has been injected into the soil. The necessity of using hand held lances increases the labor requirement, and cost.

In using lime slurry pressure injection around a building perimeter the amount of lime slurry remaining within or close to the narrow injected area is indeterminate. The lime slurry is free to migrate away from the two vertical lines defining the injected area or barrier. If the clay is desiccated or highly fractured, the lime slurry may migrate laterally great distances, both beneath and away from a building. Not only will the slurry migrate along fractures and tension cracks, but the high pumping pressure (150 psi) used in the slurry pressure injection will permit planes of weakness in the soil to be caused causing other avenues of lime slurry travel. Consequently, there is a question and doubt as to whether an adequate barrier has been or can be established which will inhibit moisture migration and restrict the shrinking and swelling of the foundation soil. This is demonstrated by Figures 16 and 18, Figures 38 and 41. It can readily be seen that variations in moisture content at depth around the perimeter of both test houses is varying with the hot and cool and wet seasons of the year, with characteristic lag time.

The use of lime slurry pressure injection around a building perimeter has completely different parameters than using the technique to stabilize a large soil mass. For a large surface area, lime slurry migration into areas previously injected is inhibited by buildup of pore pressure within the areas previously injected. The end result is a large soil mass, defined by four vertical planes which would be subjected to lateral lime slurry migration. However, the interior of the soil mass will have more uniform distribution of lime slurry than could be expected in injecting a comparatively narrow strip around a building.

# MOISTURE MIGRATION BARRIERS

## GENERAL

Six houses damaged by differential soil movements were treated by utilizing various type barriers to mitigate or minimize moisture migration. In addition, foundation soil moisture was increased 2-3 percent above the Plastic Limit. Types of barriers installed included a gravel capillary barrier, a rubbery barrier, and a lean concrete barrier. Each type of barrier was installed in a distressed house in the soil of each geologic formation being considered.

It was apparent from the beginning, that a desirable vertical barrier was very difficult to install with conventional excavation or trenching equipment presently being utilized in the construction and home building industry. Ideal equipment would be small and maneuverable to cope with directional changes at the house perimeter as well as avoiding any encroachment to adjoining properties. The equipment must also be designed to be structurally strong and powerful enough to excavate a vertical trench no less than five feet deep and have an absolute minimum width, without losing directional stability. These requirements are not as stringent for new construction, but become very important for the use of remedial techniques in existing subdivisions. Equipment available was limited to a nominal four inch trench width for an excavation depth of five feet, and the nominal four inch width rapidly becomes a six to eight inch width when excavating in desiccated materials. This will greatly increase the cost of the vertical barrier.

It is of interest to note that since the beginning of this research project, one of the major manufacturers of excavation and trenching equipment presently being utilized in the construction and home building industry has reengineered its model to date that will allow the excavating arm to be moved to either side of the drive wheels. This capability will permit trenching immediately adjacent to the house perimeter grade beam plus eliminating problems associated with directional changes of the house exterior. Further, less trenching would be required, less barrier material would be used and costs associated with a vertical barrier would be reduced accordingly. Of equal significance, would be the elimination of an area approximately two feet wide multiplied by the length of the house perimeter which would be subjected to greater climatic effects than the barrier was immediately adjacent to the house perimeter beam. The elimination of this area would also contribute to lowering costs by eliminating excavation of the horizontal area and sloping the barrier up to the bottom of the trench at the perimeter beam and then restoring the ground surface.

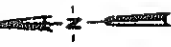
The first house around which a granular capillary barrier was placed is located at 1642 Cedar Keys Drive in Lewisville, Texas, and is founded on soil of the Eagle Ford geologic unit. The other is located at 9909 Bluffcreek Drive in Dallas, Texas, and is located in the area underlain by the Taylor Marl geologic formation. Details of the floor plan, leveling points, permanent bench mark, soils investigation, costs and increasing foundation soil moisture have previously been given. Contour surveys of each floor slab prior and subsequent to corrective actions have been reported. (1,2)

## 2.1 Vertical Movement - 1642 Cedar Keys Drive, Lewisville, Texas

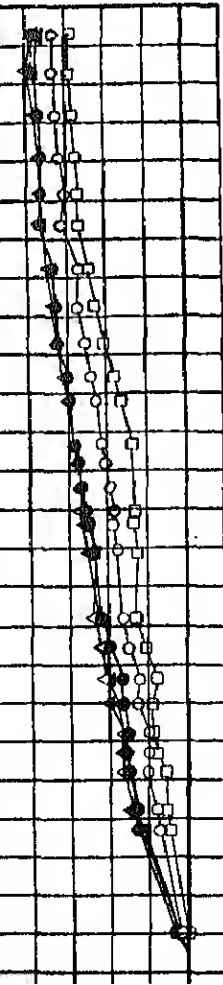
Data acquisition of vertical movements around the foundation perimeter was initiated after the capillary barrier was in place and the foundation soil moisture content increased to 2-3 percent above the Plastic Limit of the soil. The soil moisture content had to be determined by test as any computed quantity of water to be added to the soil would not be an accurate indication. This was because free water could migrate across the capillary barrier and this did occur.

The floor slab for the house at 1642 Cedar Keys Drive, Lewisville, Texas had a "cupped" shape. The perimeter edges were higher than the interior portion. Water was added to the foundation soil from the interior of the house using auger borings at selected points. Damage reversal was observed in this house within a short time after the soil moisture content was increased and an additional contour survey of differential slab elevations was performed.

Figure 20 shows the vertical movements along each side of the test house with time. The performance period is for two years or the effects of four seasonal cycles. It can be seen that the southeast corner of the house is the high point and the southwest corner the low point around the perimeter. In this area, it would be anticipated that the northeast corner would be the high point; however, the anisotropic properties of the subsoil, the effects of vegetation, and the degree of maintenance by the homeowner could account for this elevation change which approximated 0.72 inches. In analyzing the vertical movements, the magnitude of elevation change along the south side of the house is considered important. The overall change in elevation from the southwest corner to the southeast corner approximates 0.23 foot or approximately 2.76 inches. While this is a significant change in elevation, it can be seen that the change between leveling points is very uniform, which is desirable. Of equal importance is that the effects of seasonal or climatic changes are to a great extent dampened out. This is evident on the north and east sides of the house as indicated in Figure 20, and also in Figure 21 which shows the amount of differential elevation with time along each side of the house. Table 9 provides this data in tabular form.

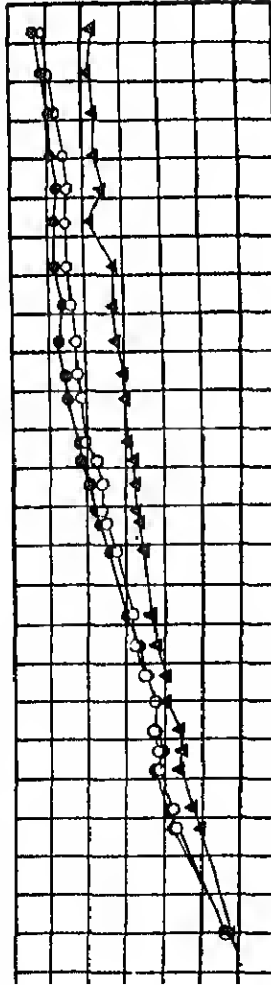


Level Pin 2 ●  
Level Pin 3 ▲  
Level Pin 4 ▲  
Level Pin 11□



EAST SIDE

Level Pin 4 ▲  
Level Pin 5 ○  
Level Pin 6 ●



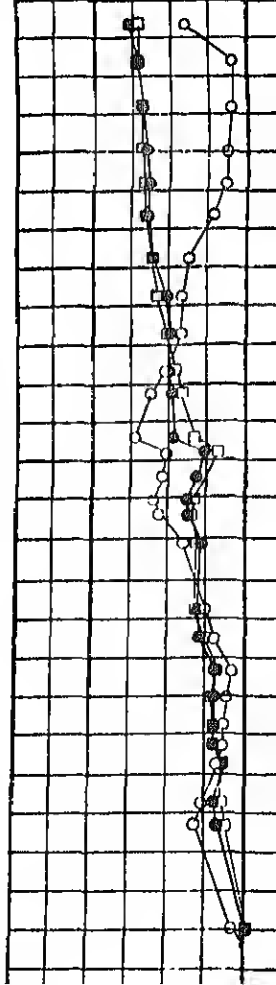
SOUTH SIDE

Level Pin 6 ●  
Level Pin 7 ▲  
Level Pin 8 ▲  
Level Pin 9 ○



WEST SIDE

Level Pin 9 ○  
Level Pin 10●  
Level Pin 11□



1 2 3

Capillary Barrier

10  
Scale Foot Formations

acquisition for the test house commenced after installation of the barrier and increase of moisture in the foundation subsoil. Again, amount of water could not be considered factual, due to free water cross the barrier, and the soil moisture content was determined by

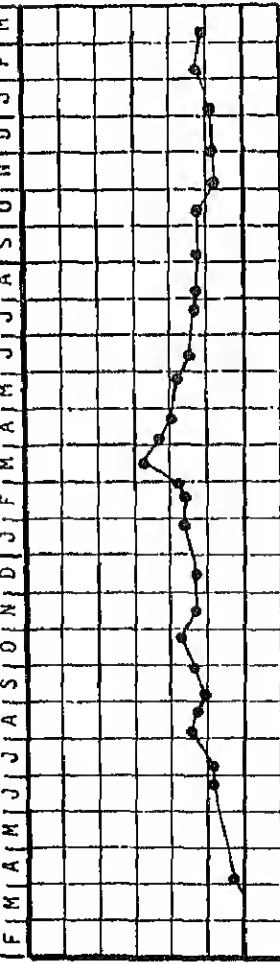
floor slab for the house at 9909 Bluffcreek, Dallas, Texas, had a slope, or the edges of the slab were lower than the slab interior. Added to the subsoil from the exterior of the house through the barrier and beneath the perimeter grade beam. While no immediate stage reversal was noted, an additional contour survey of differential elevations was performed.

Figure 22 shows the vertical movements along each side of the house as of time, and Figure 23 indicates the maximum change in elevation along each side of the house. Data presented is for a performance two years and represents the climatic effects over approximately two annual cycles. Both the northeast and southeast corners of the floor are at approximately the same elevation, with the midpoint along the east side of the perimeter beam being slightly higher. The southwest corner is lower; however, change in elevation along the short west side is significant. The south side of this house has the greatest differential movement in corners. Analyzing the configuration of the south side and the data from level pins 4, 5, 6, 7, and 8, would indicate that climate, soil, and effects of home maintenance are important considerations. The southwest corner and even more so at the change in floor plan shown at level pins 6 and 7 where essentially there are two additional vertical planes subjected to the previously mentioned considerations. The corner at level pin 6 may be postulated as being subjected to the effects of climate, as accumulated data would indicate. In effect, this may be considered an extension or continuation of the length of the test house where climatic effects are more pronounced in

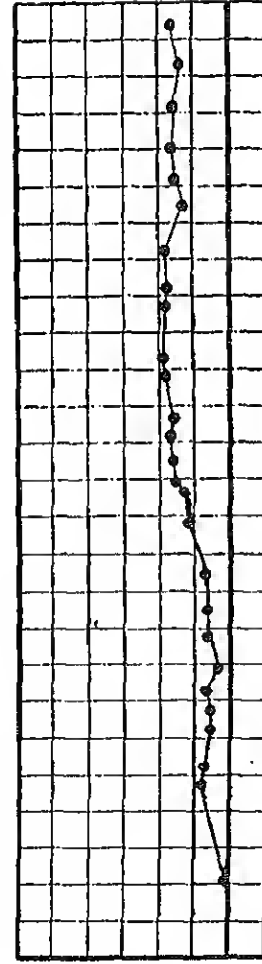
the vertical movements of all sides of the house are significant. Figure 22, the differential movements as given in Figure 23, show that the east and west sides have the greatest physical effect on the house floor slab. The change in elevation between leveling points are relatively small, indicating the effectiveness of this stabilization technique. Finally, Figures 22 and 23 indicate climatic effects are being dampened out and the change in elevation between leveling points may be attributed, to some extent, to changes in the subsoil physical properties at different locations around the perimeter of the house.



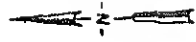
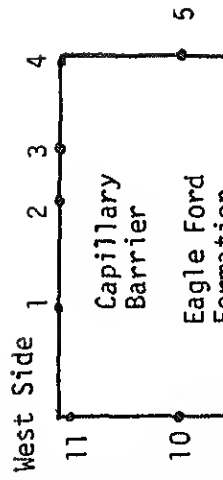
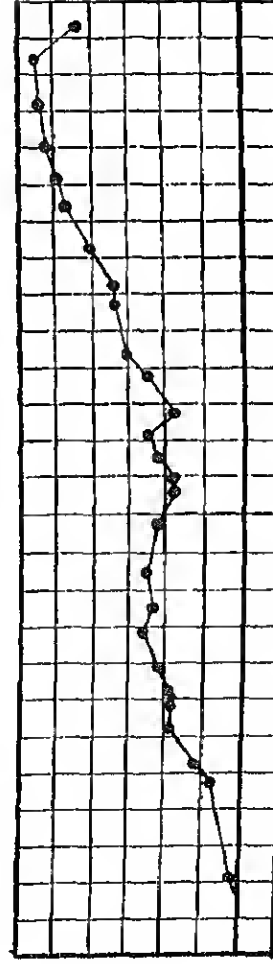
North Side



East Side



South Side



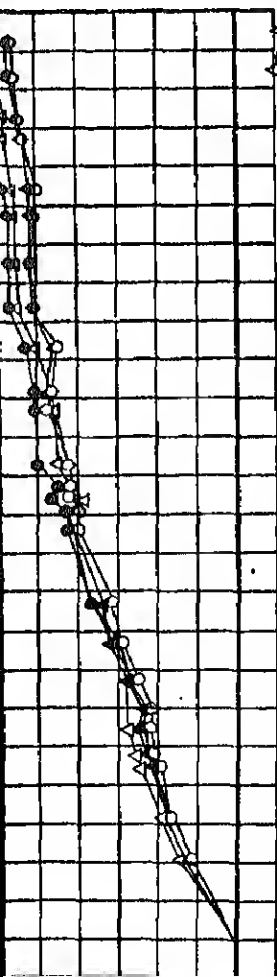
Capillary  
Barrier  
Eagle Ford  
Formation

## Differential Elevation: Lot

te	North Side			East Side			South Side			West Side		
	Ft.	In.	Cm.	Ft.	In.	Cm.	Ft.	In.	Cm.	Ft.	In.	Cm.
02-76	.010	.120	.305	.008	.096	.244	.009	.108	.274	.018	.216	
21-76	.039	.468	1.189	.039	.468	1.189	.036	.432	1.097	.040	.480	1.
09-76	.039	.468	1.189	.035	.420	1.067	.047	.564	1.433	.028	.336	
09-76	.057	.684	1.737	.030	.360	.914	.075	.900	2.286	.008	.096	
23-76	.046	.552	1.402	.030	.360	.914	.073	.876	2.225	.011	.132	
09-76	.042	.504	1.280	.033	.396	1.006	.080	.960	2.438	.014	.168	
29-76	.055	.660	1.676	.012	.144	.366	.089	1.068	2.713	.022	.264	
21-76	.072	.864	2.195	.026	.312	.792	.107	1.284	3.261	.022	.264	
16-76	.056	.672	1.707	.030	.360	.914	.092	1.104	2.804	.017	.204	
09-76	.056	.672	1.707	.030	.360	.914	.100	1.200	3.048	.015	.180	
27-77	.067	.804	2.042	.045	.540	1.372	.091	1.092	2.774	.025	.300	
18-77	.066	.792	2.012	.053	.636	1.615	.073	.876	2.225	.046	.552	1.
28-77	.074	.888	2.255	.056	.672	1.707	.072	.864	2.195	.058	.696	1.
14-77	.120	.144	3.658	.060	.720	1.829	.089	1.068	2.713	.091	1.092	2.
04-77	.104	1.248	3.170	.069	.828	2.103	.104	1.248	3.170	.068	.816	2.
19-77	.082	.984	2.499	.059	.708	1.798	.070	.840	2.134	.080	.960	2.
24-77	.072	.864	2.195	.075	.900	2.286	.098	1.176	2.987	.045	.540	1.
10-77	.065	.780	1.981	.078	.936	2.377	.126	1.512	3.840	.014	.168	
08-77	.060	.720	1.829	.074	.888	2.255	.149	1.788	4.542	.017	.204	
05-77	.054	.648	1.646	.067	.804	2.042	.148	1.776	4.511	.031	.372	
07-77	.055	.660	1.676	.075	.900	2.286	.169	2.028	5.151	.049	.588	1.
10-77	.055	.660	1.676	.056	.672	1.707	.201	2.412	6.126	.090	1.080	2.
04-77	.045	.540	1.372	.061	.732	1.859	.206	2.472	6.279	.104	1.248	3.
01-77	.047	.564	1.433	.067	.804	2.042	.214	2.568	6.523	.105	1.260	3.
04-78	.048	.576	1.463	.064	.768	1.951	.220	2.640	6.706	.114	1.368	3.
16-78	.054	.648	1.646	.061	.732	1.859	.232	2.784	7.071	.122	1.464	3.
8-78	.047	.564	1.433	.079	.948	2.408	.183	2.196	5.578	.072	.864	2.

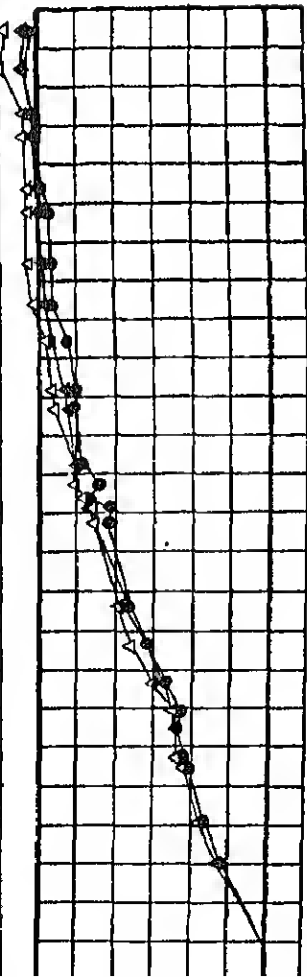
# NORTH SIDE

Level Pin 1 ○  
Level Pin 2 ●  
Level Pin 10 △  
Level Pin 11 ▲



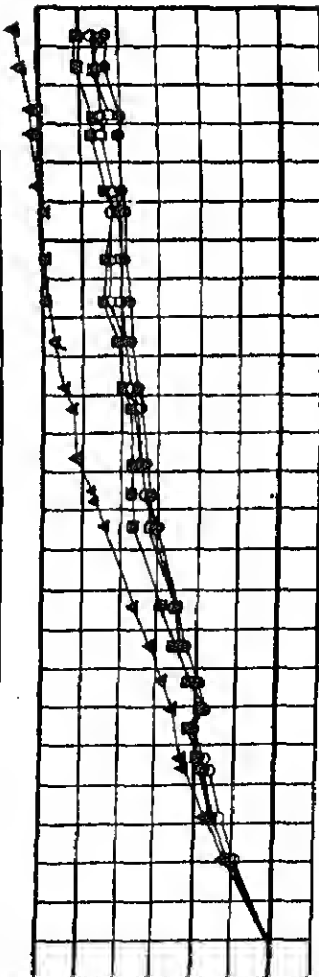
# EAST SIDE

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Level Pin 3 △  
Level Pin 4 ▲



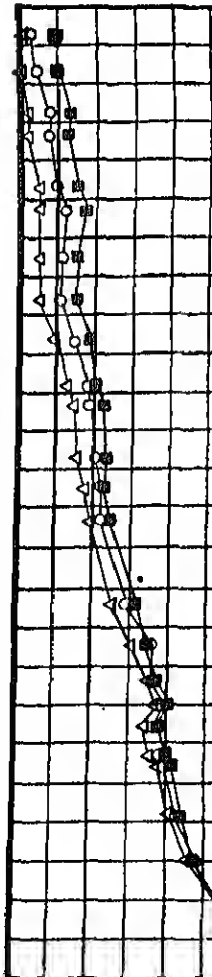
# SOUTH SIDE

Level Pin 4 ▲  
Level Pin 5 ○  
Level Pin 6 ●  
Level Pin 7 □  
Level Pin 8 ■



# WEST SIDE

Level Pin 8 ■  
Level Pin 9 ○  
Level Pin 10 △



11 1

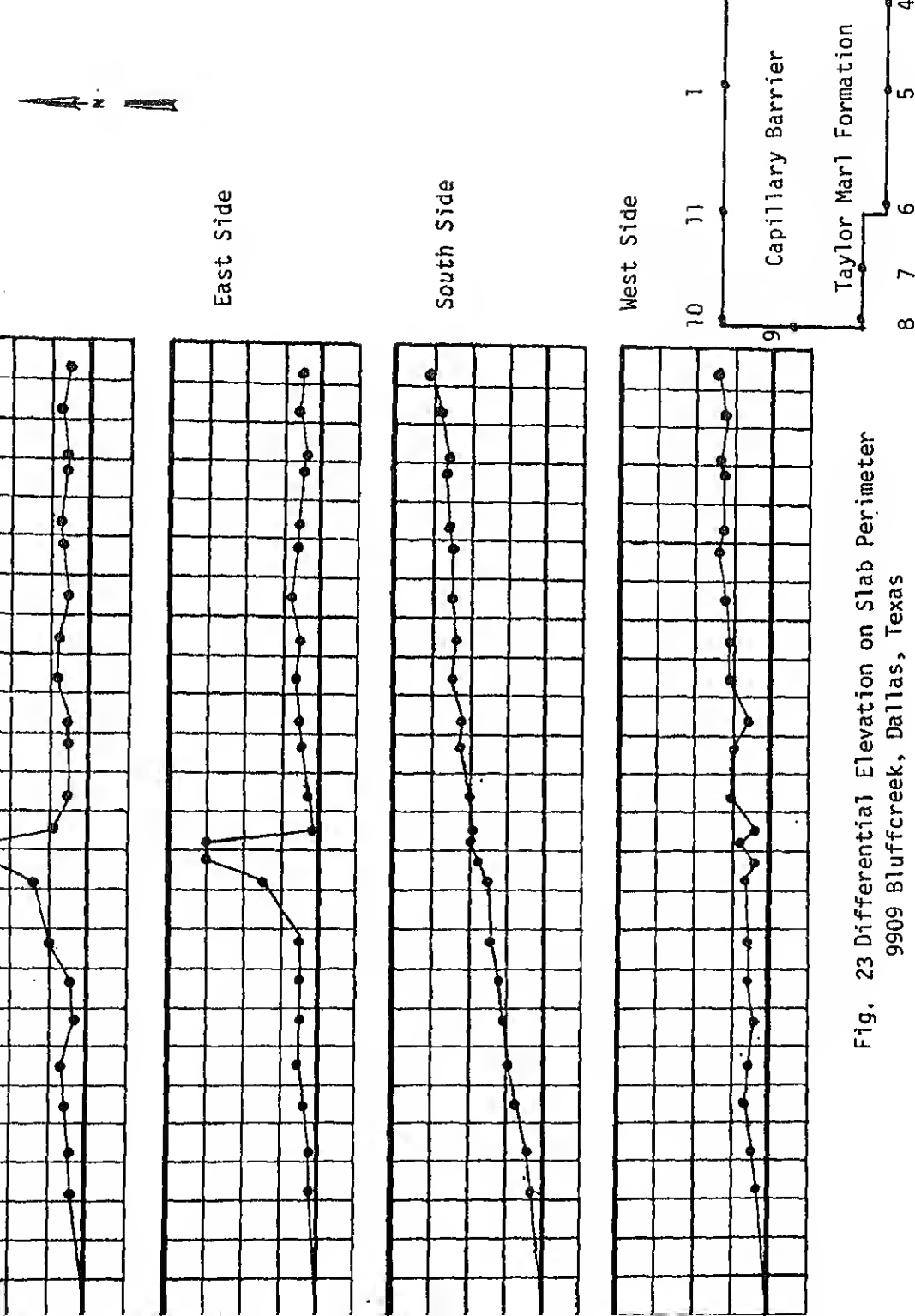


Fig. 23 Differential Elevation on Slab Perimeter  
9909 Bluffcreek, Dallas, Texas

Differential Elevation: Lot

	North Side			East Side			South Side			West Side	
	Ft.	In.	Cm.	Ft.	In.	Cm.	Ft.	In.	Cm.	Ft.	In.
2-76	.012	.144	.366	.008	.096	.244	.012	.144	.366	.010	.120
5-76	.017	.206	.518	.008	.096	.244	.019	.228	.579	.020	.240
3-76	.028	.336	.853	.018	.216	.549	.034	.408	1.036	.029	.348
6-76	.019	.228	.579	.018	.216	.549	.033	.396	1.006	.027	.324
4-76	.021	.348	.640	.024	.288	.732	.040	.480	1.219	.021	.252
0-76	.007	.084	.213	.016	.192	.488	.034	.408	1.036	.019	.228
2-76	.010	.120	.305	.022	.264	.671	.046	.552	1.402	.014	.168
6-76	.014	.168	.427	.024	.288	.732	.041	.492	1.250	.017	.204
8-76	.014	.168	.427	.023	.276	.701	.049	.588	1.494	.027	.326
1-76	.045	.540	1.732	.022	.264	.671	.058	.696	1.768	.027	.326
7-77	.057	.684	1.737	.066	.792	2.012	.068	.816	2.073	.030	.360
1-77	.113	1.356	3.444	.124	1.488	3.780	.076	.912	2.316	.015	.180
4-77	.103	1.236	3.139	.127	1.524	3.871	.082	.984	2.499	.034	.408
4-77	.039	.468	1.189	.008	.096	.244	.091	.972	2.469	.015	.180
5-77	.022	.264	.671	.029	.348	.884	.097	1.164	2.956	.028	.336
0-77	.027	.324	.823	.009	.108	.274	.086	1.032	2.621	.048	.576
3-77	.025	.300	.762	.023	.276	.701	.091	1.094	2.774	.045	.540
6-77	.026	.312	.792	.024	.288	.732	.089	1.068	2.713	.024	.288
2-77	.038	.456	1.158	.028	.336	.853	.103	1.236	3.139	.048	.576
1-77	.033	.396	1.006	.024	.288	.732	.100	1.200	3.048	.048	.576
5-77	.028	.336	.853	.032	.384	.975	.105	1.260	3.200	.051	.612
1-77	.036	.432	1.097	.028	.336	.853	.105	1.260	3.200	.058	.696
1-77	.043	.516	1.311	.025	.300	.762	.109	1.308	3.322	.051	.612
0-77	.034	.408	1.036	.020	.240	.610	.110	1.320	3.353	.051	.612
6-78	.037	.444	1.128	.016	.192	.488	.109	1.308	3.322	.055	.660
3-78	.036	.432	1.097	.029	.348	.884	.103	1.236	3.139	.055	.660
0-78	.027	.329	.823	.026	.312	.792	.108	1.296	3.292	.060	.720

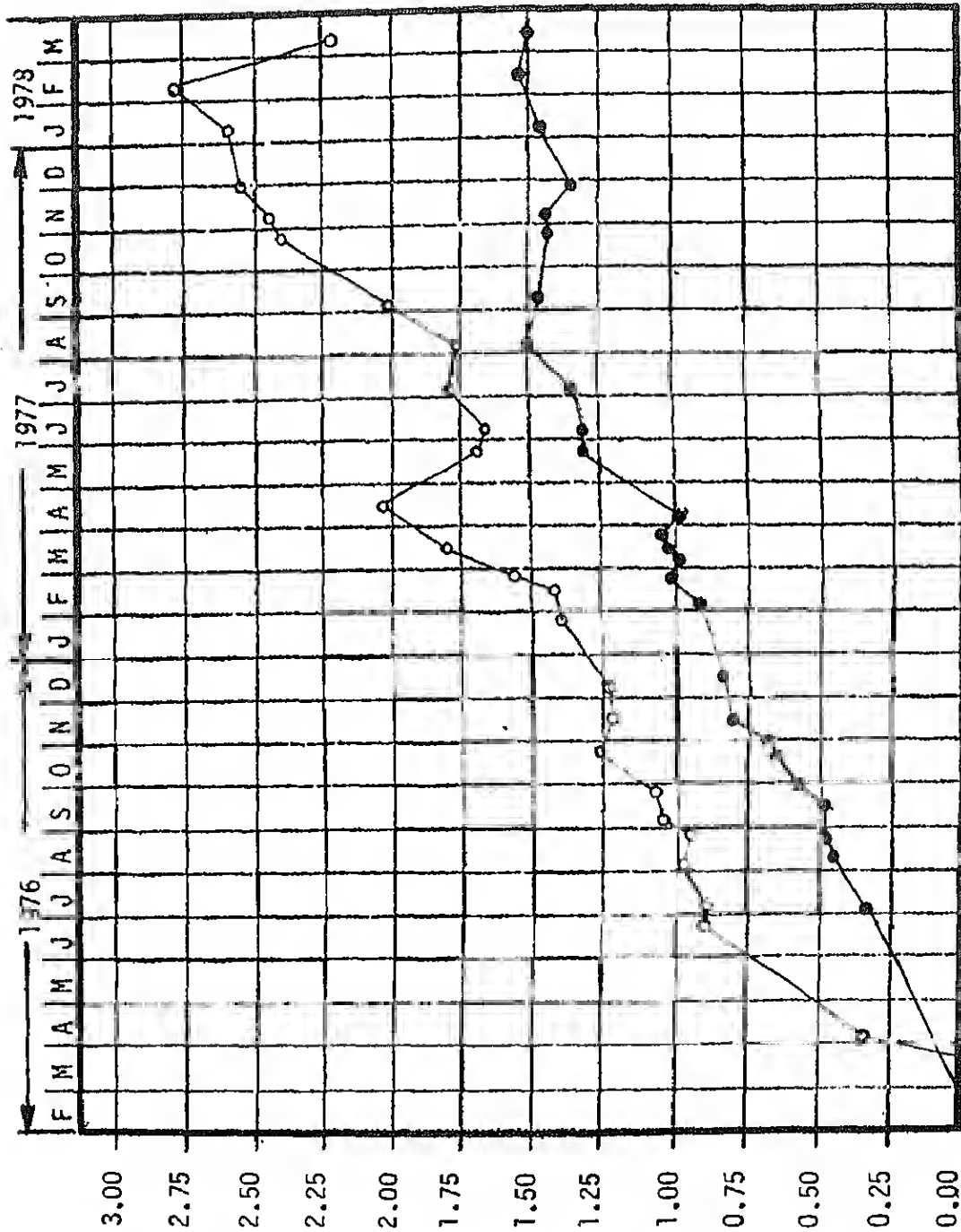
Previously stated, it was observed during this test program the formation appeared to be more dense than the Eagle Ford geologic unit. Figures 4, and Tables 11 and 12, show a comparison of the capillary barrier stabilization technique. Values plotted are absolute movements and indication of the activity of each formation for the period of time in this study. It may be possible, at some time in the future, migration of any free water to cross the capillary barrier and be taken up by the mass of subsoil encompassed by the barrier. This could result in additional vertical movement in the Taylor formation if the soil clay minerals require additional water to satisfy the mineral double layer requirement. At present time, the maximum vertical movement around the foundation is greater in the Taylor formation than the movement in the Eagle Ford geologic unit for the capillary barrier stabilization technique.

#### Soil Moisture-Temperature Characteristics - 1642 Cedar Keys Drive, Lewisville, Texas

The acquisition for variation in soil moisture content with time, as shown in Figure 25, commenced upon completion of actions associated with installation of the capillary barrier as a subsoil stabilization technique. It is apparent that the increase in moisture content in the subsoil at all depths of interest was relatively successful. The narrow band width of soil moisture contents for each depth and with time indicates the stability of the installation and effectiveness of the capillary barrier in inhibiting moisture loss from the subsoil.

An anomaly is apparent for the curves given in Figure 25, at a depth of 10 feet below the perimeter beam. The moisture cells installed in the boring on the west side of the house indicate a moisture content significantly less than on the other three sides of the test house. This anomaly may be due to variation of soil properties at this depth and on the east side of the house. The investigation boring log indicated a natural moisture content approximately 10 percent above the Plastic Limit at this depth of interest and it is probable that less than desired intimacy of contact is existing between the soil and the moisture cell.

The average natural soil moisture content from the soils investigation was 10 percent to a depth of five feet. The average Plastic Limit to the subsoil was 20 percent. Figure 25 shows the moisture contents at all depths of the subsoil to be at least 2-3 percent above the Plastic Limit and to have relatively constant values with time. The exception to this state-ment has previously been discussed. In addition, climatic effects are not observed affecting subsoil moisture to any significant degree, within the soil mass stabilized by the capillary barrier.

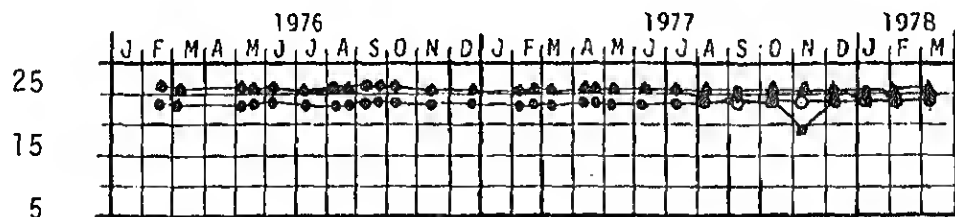
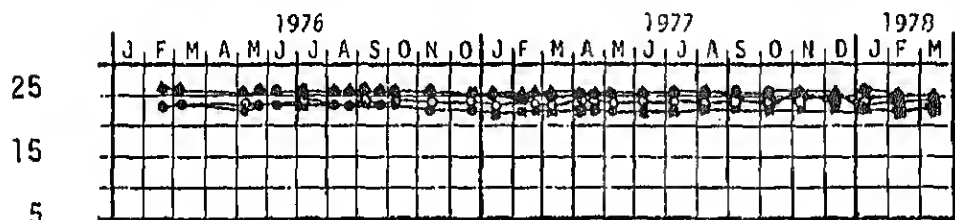
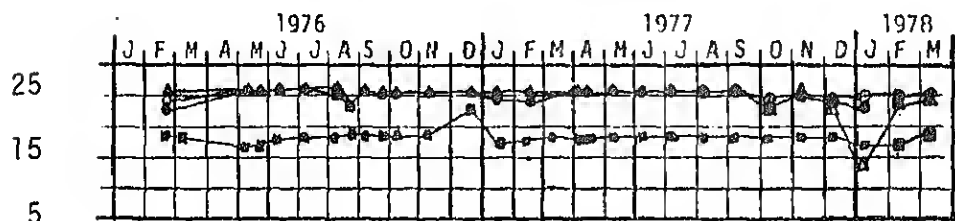
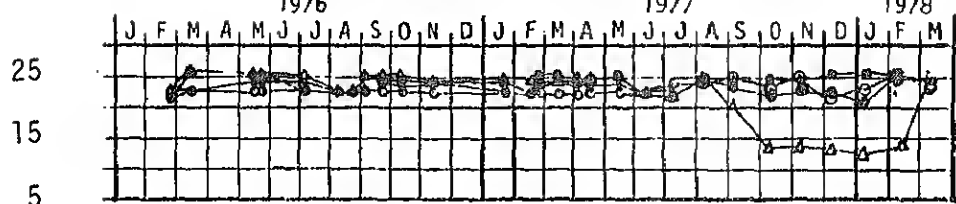


## Maximum Perimeter Differential Movement

Date	Movement		
	Feet	Inches	Cm.
Apr. 2, 1976	.027	.324	.823
June 21, 1976	.076	.912	2.316
July 9, 1976	.075	.900	2.286
Aug. 9, 1976	.083	.996	2.530
Aug. 23, 1976	.079	.948	2.408
Sep. 9, 1976	.086	1.032	2.621
Sep. 29, 1976	.089	1.068	2.713
Oct. 21, 1976	.108	1.296	3.292
Nov. 16, 1976	.100	1.200	3.048
Dec. 9, 1976	.100	1.200	3.048
Jan. 27, 1977	.116	1.392	3.536
Feb. 18, 1977	.119	1.428	3.627
Feb. 28, 1977	.130	1.560	3.962
Mar. 14, 1977	.150	1.800	4.572
Apr. 14, 1977	.172	2.064	5.243
May 24, 1977	.143	1.716	4.359
June 10, 1977	.140	1.680	4.267
July 8, 1977	.149	1.788	4.542
Aug. 5, 1977	.148	1.776	4.511
Sep. 7, 1977	.169	2.028	5.151
Oct. 10, 1977	.201	2.412	6.126
Nov. 4, 1977	.206	2.472	6.279
Dec. 1, 1977	.214	2.568	6.523
Jan. 4, 1978	.220	2.640	6.706
Feb. 6, 1978	.232	2.784	7.071
Mar. 8, 1978	.183	2.196	5.578
Apr. 3, 1978	.165	1.980	5.029



Date	Movement		
	Feet	Inches	Cm.
June 2, 1976	.022	.264	.671
July 5, 1976	.029	.328	.884
Aug. 13, 1976	.038	.456	1.158
Aug. 26, 1976	.040	.480	1.219
Sep. 14, 1976	.040	.480	1.219
Sep. 30, 1976	.048	.576	1.463
Oct. 22, 1976	.054	.648	1.646
Oct. 26, 1976	.057	.684	1.737
Nov. 18, 1976	.068	.816	2.073
Dec. 21, 1976	.071	.852	2.164
Feb. 7, 1977	.078	.936	2.377
Feb. 21, 1977	.084	1.008	2.560
Mar. 4, 1977	.082	.984	2.499
Mar. 14, 1977	.084	1.008	2.560
Mar. 25, 1977	.105	1.260	3.200
Apr. 11, 1977	.082	.984	2.499
May 23, 1977	.112	1.344	3.414
June 9, 1977	.108	1.296	3.292
July 12, 1977	.114	1.368	3.475
Aug. 11, 1977	.124	1.488	3.780
Sep. 15, 1977	.123	1.476	3.748
Oct. 21, 1977	.122	1.464	3.719
Nov. 11, 1977	.121	1.452	3.688
Dec. 20, 1977	.112	1.344	3.414
Jan. 5, 1978	.121	1.452	3.688
Feb. 13, 1978	.130	1.560	3.962
Mar. 10, 1978	.125	1.500	3.962
Apr. 3, 1978	.129	1.548	3.932
May 15, 1978	.127	1.524	3.871



- North Side Boring
- East Side Boring
- △ South Side Boring
- West Side Boring

\* Refers to Depths Below Perimeter Grade Beam

Fig. 25 Soil Moisture Content - Capillary Barrier  
1642 Cedar Keys Drive, Lewisville, Texas

The variation of the subsoil temperature with time and for different depths is given in Figure 26. These curves show the characteristic sine wave with changes in climatic temperatures and without significant lag time. At depths of interest, the amplitude of the curve decreases with depth of soil cover. Temperature means and standard deviations are given in Table 14, page 59.

#### 4.2.5 Soil Moisture-Temperature Characteristics - 9909 Bluffcreek, Dallas, Texas

Data acquisition for monitoring subsoil moisture characteristics with time is given in Figure 27. Acquisition commenced upon completion of actions associated with the use of a capillary barrier as a subsoil stabilization technique. It can be seen that the moisture content to depths of interest were increased and maintained well above the Plastic Limit of the soil. Figure 27 also illustrates the dense characteristics of the Taylor formation. The fluctuation of the soil moisture continued over a period of approximately 8-9 months before stabilizing into a narrow band width. It is noted that the fluctuation of magnitude of soil moisture was in a range above the Plastic Limit which was desired.

The average natural moisture content of the soil within the depths of interest was 13.8 percent, with the largest variation of moisture content below the Plastic Limit being 7.7 percent. The average Plastic Limit within the depths of interest was 19.4 percent with the variation being approximately 2 percent. It is emphasized that any free water associated with climate or home maintenance is not inhibited from crossing the capillary barrier and being taken into the foundation soil, if the soil moisture demand of the clay minerals is deficient in satisfying the double layer water requirement. The objective for increasing the subsoil moisture content was to be minimum of 2-3 percent above the Plastic Limit of the soil. Any increase in moisture beyond that minimum was a more positive action.

The variation of the soil temperature with time and for different depths is given in figure 28. Again, these curves show a characteristic sine wave with time and without lag time due to climate. The agreement of data at all depths is exceptional and lends credence to the accuracy of other field information. Temperature means and standard deviations are given in Table 14, page 59.

#### 4.2.6 Comparison of Moisture-Temperature Characteristics

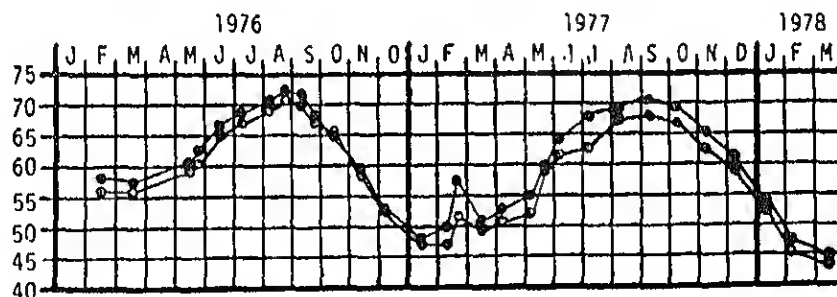
The variation of subsoil moisture content with time for these two test houses utilizing a capillary barrier as a subsoil stabilization technique on two geologic formations are similar. From the soil investigation, it



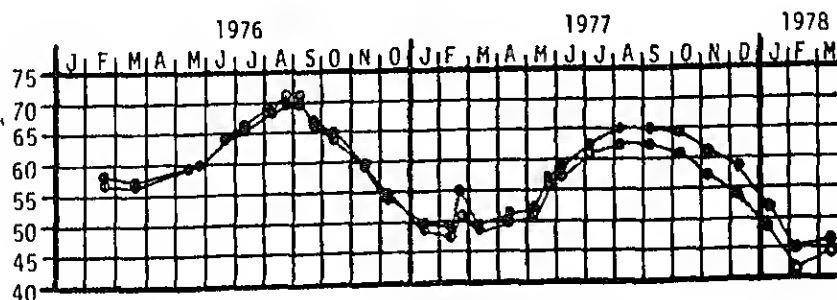
Depth 2.5



Depth 4



Depth 5.5



-Key-

- North and South Side Average
- East and West Side Average

Depths refer to feet below grade beam.

Table 13

## TEMPERATURE MEANS AND STANDARD DEVIATION

Mar Keys Drive, Lewisville, TX

## Capillary Barrier

*Depth (ft)	Depth (ft)		
	1	2.5	4
59.24	59.67	58.88	56.70
11.25	9.42	8.71	8.58
62.79	62.78	61.95	59.75
9.82	8.48	7.13	6.42
63.24	59.83	60.30	61.23
9.41	8.59	7.06	7.27
61.10	dead	60.70	58.85
9.88		7.95	7.31

Table 14

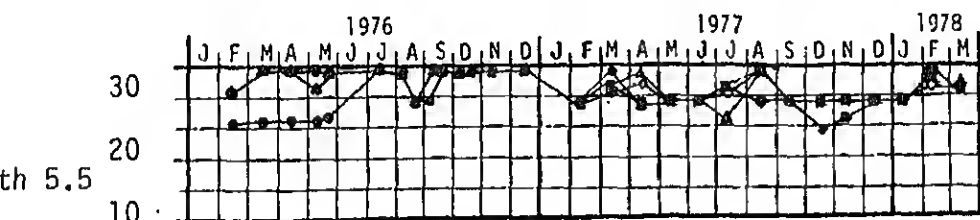
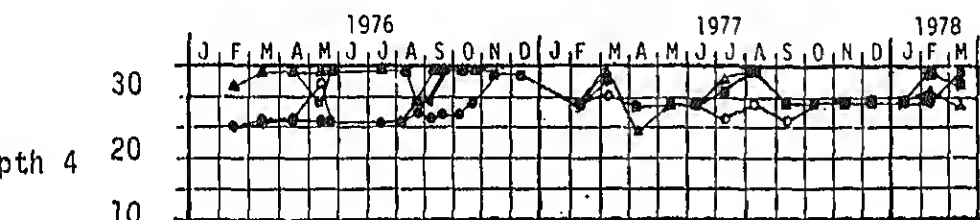
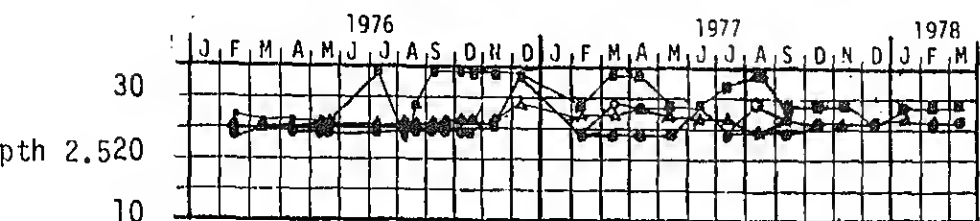
## TEMPERATURE MEANS AND STANDARD DEVIATION

9909 Bluffcreek, Dallas, TX

## Capillary Barrier

Location	*Depth (ft)		
	1	2.5	4
North	59.02 11.12	59.70 9.56	58.95 8.98
East	61.67 9.57	58.70 8.94	58.71 8.05
South	62.43 9.08	61.38 8.45	57.10 8.85
West	57.43 10.20	60.15 8.74	58.43 7.90

th refers to feet below grade beam.

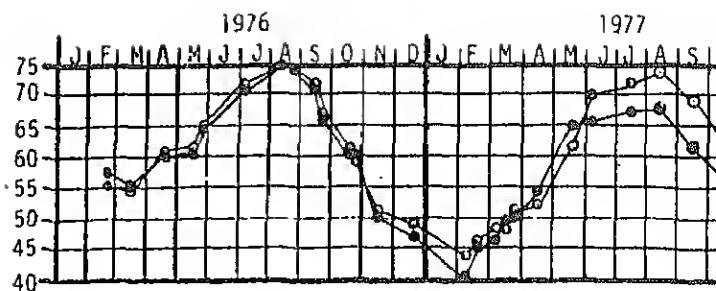


- North Side Boring
- East Side Boring
- △ South Side Boring
- West Side Boring

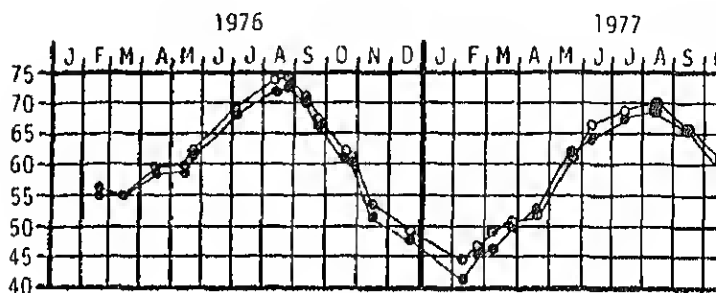
\* Refers to Depths Below Perimeter Grade Beam

Fig. 27 Soil Moisture Content - Capillary Barrier  
9909 Bluffcreek, Dallas, Texas

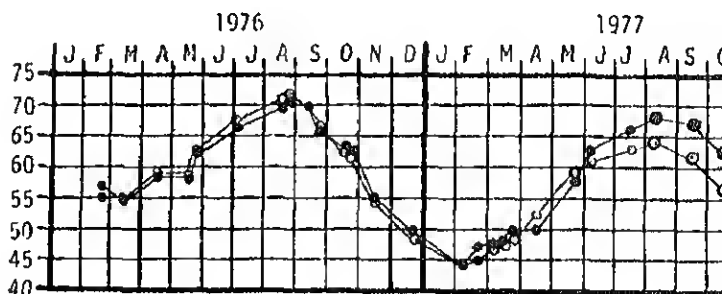
\* Depth 1



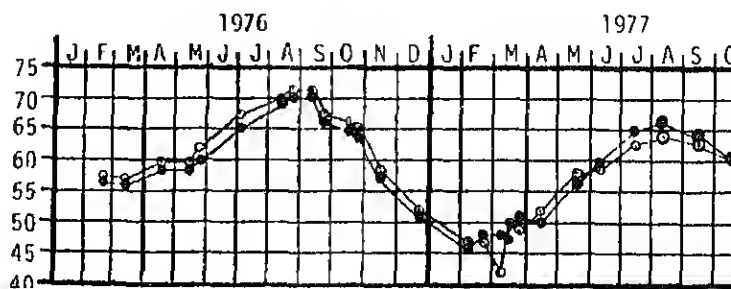
Depth 2.5



Depth 4



Depth 5.5



Soil Temperature ( $^{\circ}$  F)

3.8 percent and a maximum variation of 7.7 percent below the limit. The Plastic Limit of the soil within the depths of interest percent. The index properties of the soils beneath both houses appear to be very similar if soil was a homogeneous and isotropic. The significant variable for these values is the natural soil content, which is approximately 3.5 percent lower for the house at creek and located on the Taylor formation.

Significant interest is the difference in the percentages of montmorillonite clay minerals in the upper five feet of subsoil at the two locations. The house at 1642 Cedar Keys Drive, Lewisville, Texas, and the Eagle Ford formation, contains an average of 15 percent of montmorillonite clay minerals within a five foot depth. The house at 9909 , Dallas, Texas, and located on the residual soils of the Taylor formation contained an average of approximately 34.6 percent Montmorillonite clay minerals within a five foot depth from the soil surface. This amounted to an increase of approximately 19.6 percent Montmorillonite clay for the test house located on the Taylor formation.

Consequently, the Taylor formation has the potential to exhibit more shrinkage than the soils of the Eagle Ford formation. This volume change could be related to a change in water content of the soil. Figures 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55 and 59, show moisture contents in the foundation soils, at various band widths around the perimeter, at both test houses have remained relatively constant with time at all depths of interest. These data would indicate that the soil encompassed by the capillary barrier to be relatively

For comparison of Figures 26 and 28 , pages 60 and 63 , for subsoil temperature variations do not indicate significant differences. Variation of temperature with depth is essentially a function of climate. Within an appropriate time frame, this would not be a significant variable for magnitude in vertical movement. Both referenced figures give an indication of the insulation properties of the soil. Further justification is given by the values of temperature means and standard deviations with depth for both houses given in Tables 13 and 14 , page 64 .

#### RECYCLED RUBBER IMPERVIOUS BARRIERS

Impervious barriers made of recycled rubber were installed around two test houses previously damaged by differential movement of the floor slab. The first house was located around the house located at 461 Sweetbriar Drive in Lewisville, Texas. The second house included in this study is located at 1314 Athens Drive in Mesquite, Texas. This house is founded on the residual soils of the Eagle Ford formation.

Details of floor plans, trenching, rubber barrier, instrumentation, and data collection are given in the foundation soil



moisture, and soils investigation have previously been given. In addition, contour surveys of each floor slab plan prior and subsequent to taking corrective actions have also been reported. (1,2)

### 4.3.1 Vertical Movement - 461 Sweetbriar Drive, Lewisville, Texas

Data acquisition of vertical movements around the foundation perimeter was initiated after the rubber barrier was in place and the foundation soil moisture content increased a minimum of 2-3 percent above the Plastic Limit. Approximately 8,381 gallons of water were added to the subsoil encompassed by the rubber barrier. The floor slab at 461 Sweetbriar, Lewisville, Texas had a "cupped" configuration. The perimeter edges were higher than the interior of the slab. Water was added at certain points through the rubber barrier on the outside of the house and at selected locations through the floor slab on the interior, depending on elevation data.

Figure 29 shows the vertical movements along each side of the test house varying with time. The performance period is for approximately 2 years, which illustrates climatic effects over four seasonal cycles. It is seen that the high point of the perimeter occurs at level pin 3, or the midpoint on the east side of the test house. The low point on the perimeter occurs at the Southwest corner and the approximate midpoint of the West side, level pins 7 and 8 respectively. Of significance, is the relative uniformity of movement between leveling pins. Equally significant is the change in elevation from the high to the low point on the house is approximately 1.56 inches across the long side of the house during January 1978. It would appear that climatic changes are being dampened out and the foundation on subsoil is relatively stable. The variations in vertical movement could be attributed to variations in the soil properties within the soil mass encompassed by the rubber barrier. Figure 30 illustrates the differential elevation along each side of the house varying with time which shows these variations in vertical movements along each side of the test house. The information in tabular form is also given in Table 15.

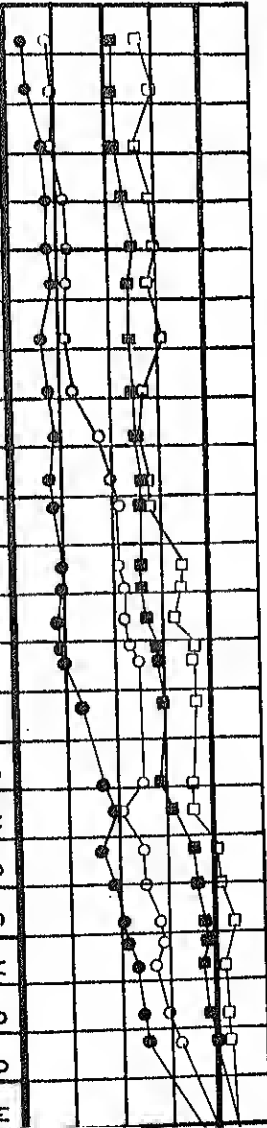
### 4.3.2 Vertical Movement - 1314 Athens Street, Mesquite, Texas

Data acquisition of vertical movements for this test house located on hills of the Taylor formation was initiated after all actions associated with utilizing a rubber vertical barrier to inhibit moisture migration caused by climatic effects were complete. Approximately 15,610 gallons of water were added to the foundation subsoil encompassed by the rubber barrier. This test house floor slab had a "domed" shape and water was introduced into the subsoil in the same manner as discussed in Section 4.3.1.

Figure 31 shows the vertical movement along each side of the test house as a function of time. Again, the period of data acquisition was for two

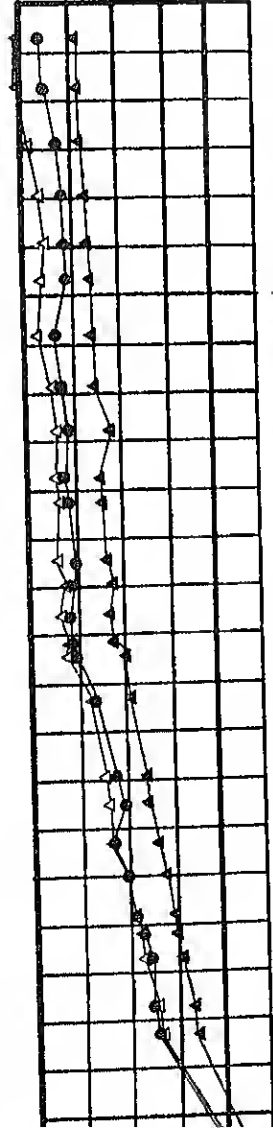
NORTH SIDE

- Level Pin 1 ○
- Level Pin 2 ●
- Level Pin 9 □
- Level Pin 10 ■



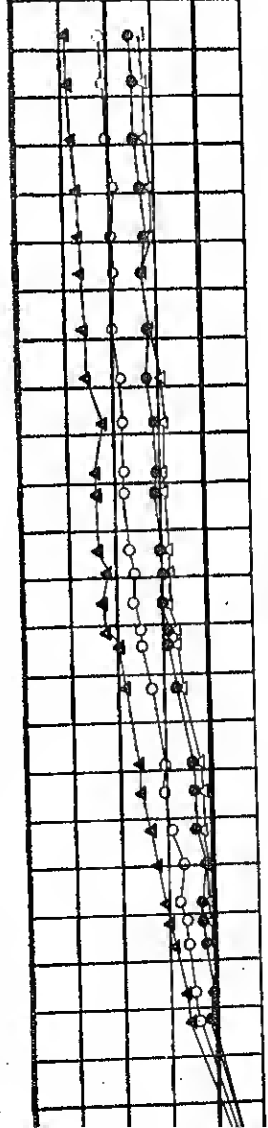
EAST SIDE

- Level Pin 2 ●
- Level Pin 3 ▲
- Level Pin 4 ▲



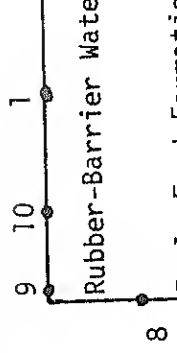
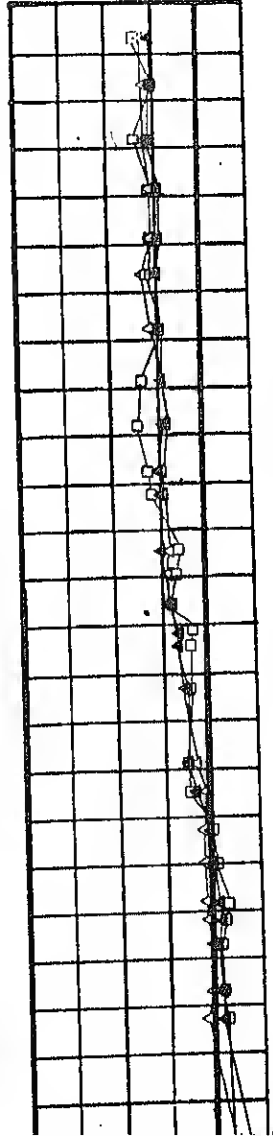
SOUTH SIDE

- Level Pin 4 ▲
- Level Pin 5 ○
- Level Pin 6 ●
- Level Pin 7 ▲

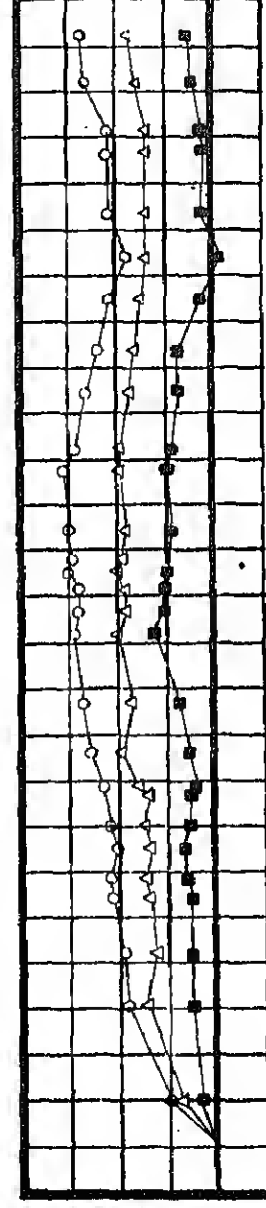
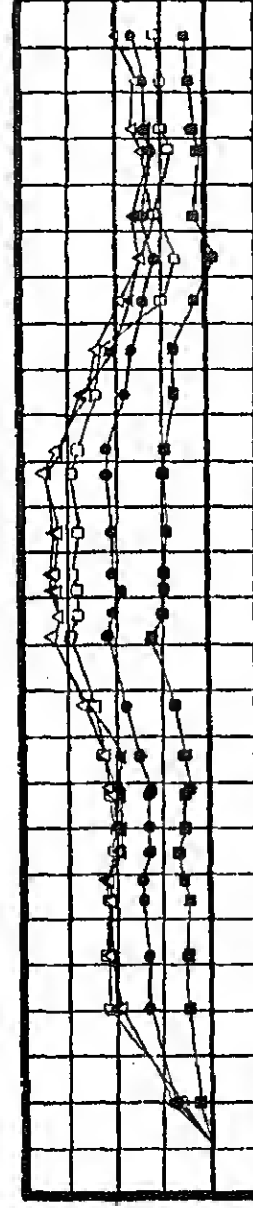
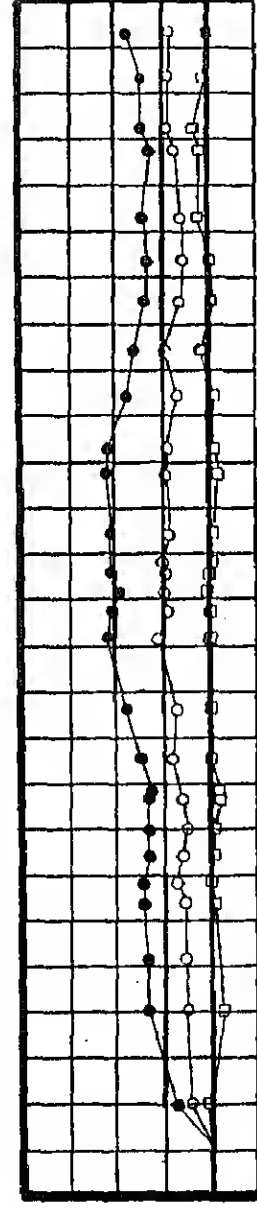
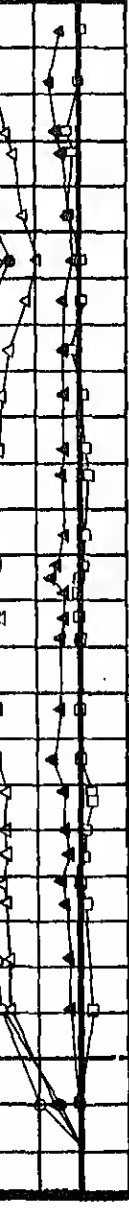


WEST SIDE

- Level Pin 7 ▲
- Level Pin 8 ▲
- Level Pin 9 □







EAST SIDE

Level Pin 5 □  
Level Pin 6 ○  
Level Pin 7 ○

SOUTH SIDE

Level Pin 7 ●  
Level Pin 8 ▲  
Level Pin 9 ▲  
Level Pin 10 □  
Level Pin 11 ■

WEST SIDE

Level Pin 11 ■  
Level Pin 12 ○  
Level Pin 1 ○

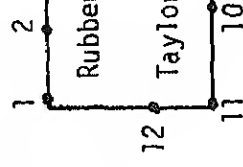


Fig. 31 Vertical Movement of Slab Perimeter  
1314 Athens Street, Mesquite, Texas

perimeter occurs at the Southwest corner or at level pin 11. The difference in elevation between the West side corners approximates 1.2 inches for January 1978. Vertical movement appeared to peak approximately six months earlier and all sides of the house appear to be stabilizing.

It would be expected the high point on the perimeter to be the North corner and this deviation may be due to the soil properties in this highly expansive formation. Significantly, the change in vertical movements along each side are stabilizing and differential elevations between leveling points are becoming relatively uniform. Figure 32 and Table 16 illustrate the relative stability around the test house perimeter.

### 3.3 Comparison of Vertical Movements

The maximum vertical movement for the test house at 461 Sweetbriar Drive, Lewisville, Texas, is greater than the maximum vertical movement of the house at 1314 Athens Street, Mesquite, Texas. The magnitude of the differential elevations along each side of the house is less for the house on the Eagle Ford formation. Further, variations of differential movement with time are not as extreme for the house on the Eagle Ford formation. The Taylor formation is considered the more active of the two geologic units and a comparison of Figures 29 and 30, pages 63 and 64 with Figures 31 and 32, pages 65 and 66 support this statement.

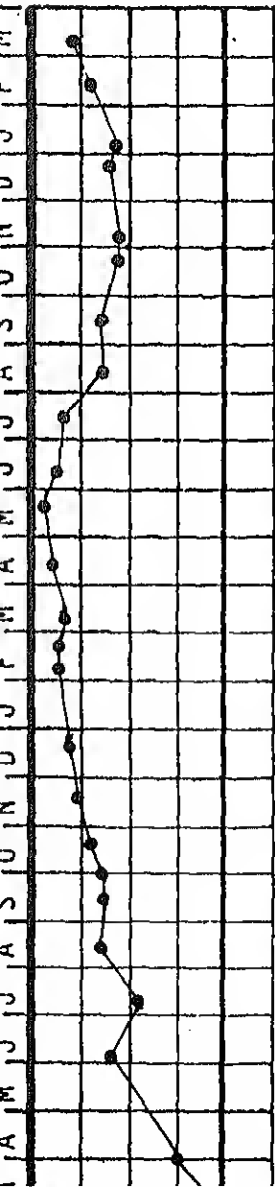
Figure 33 and Tables 17 and 18 were generated by considering the high and the low point around the perimeter of each test house and the expected variation of movement with time. Consequently, these are absolute values and give an indication of the comparative activity of the foundation soils beneath the two test houses on the two geologic formations.

As the foundation soils for both test houses are encompassed by a relatively impermeable vertical barrier, the data given is an indication of the activity of each soil mass in adjusting to a stable configuration. The amount of deviation or abrupt changes of significant magnitude from a smooth curve was considered an indication of activity within the encompassed soil mass. Figure 33 illustrates this concept and shows the soil mass beneath the house on the Eagle Ford formation approaching relative stability, while the soil mass beneath the house located on the Taylor formation is still undergoing significant adjustment.

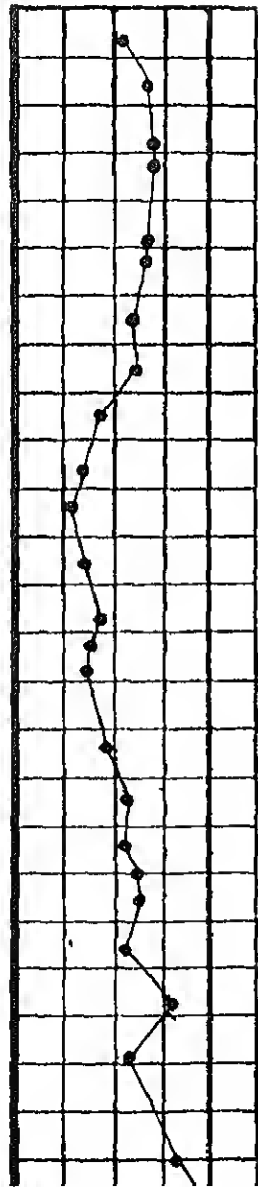
### 3.4 Soil Moisture-Temperature Characteristics - 461 Sweetbriar Drive, Lewisville, Texas

Data acquisition for variation in soil moisture content with time, as given in Figure 34, commenced upon completing all tasks associated with

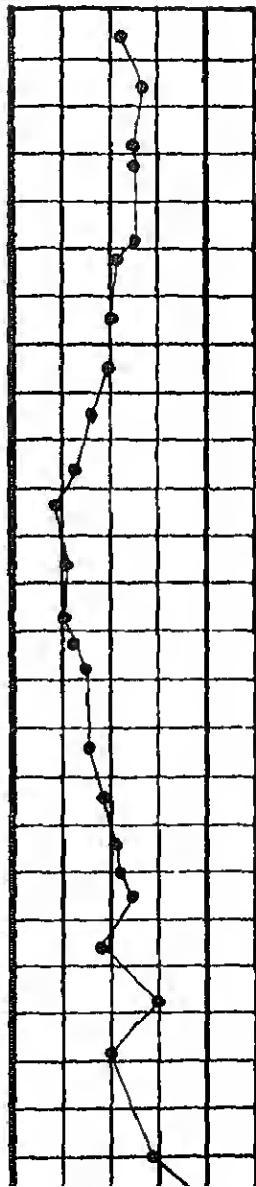
North Side



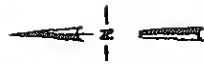
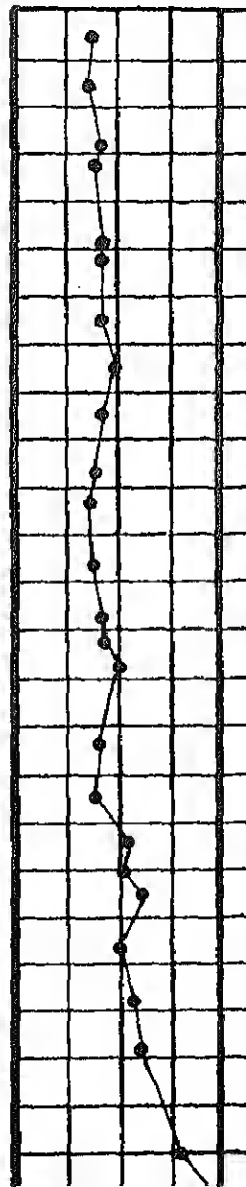
East Side



South Side



West Side



1  
2  
3  
4  
Rubber Barrier  
Water  
12

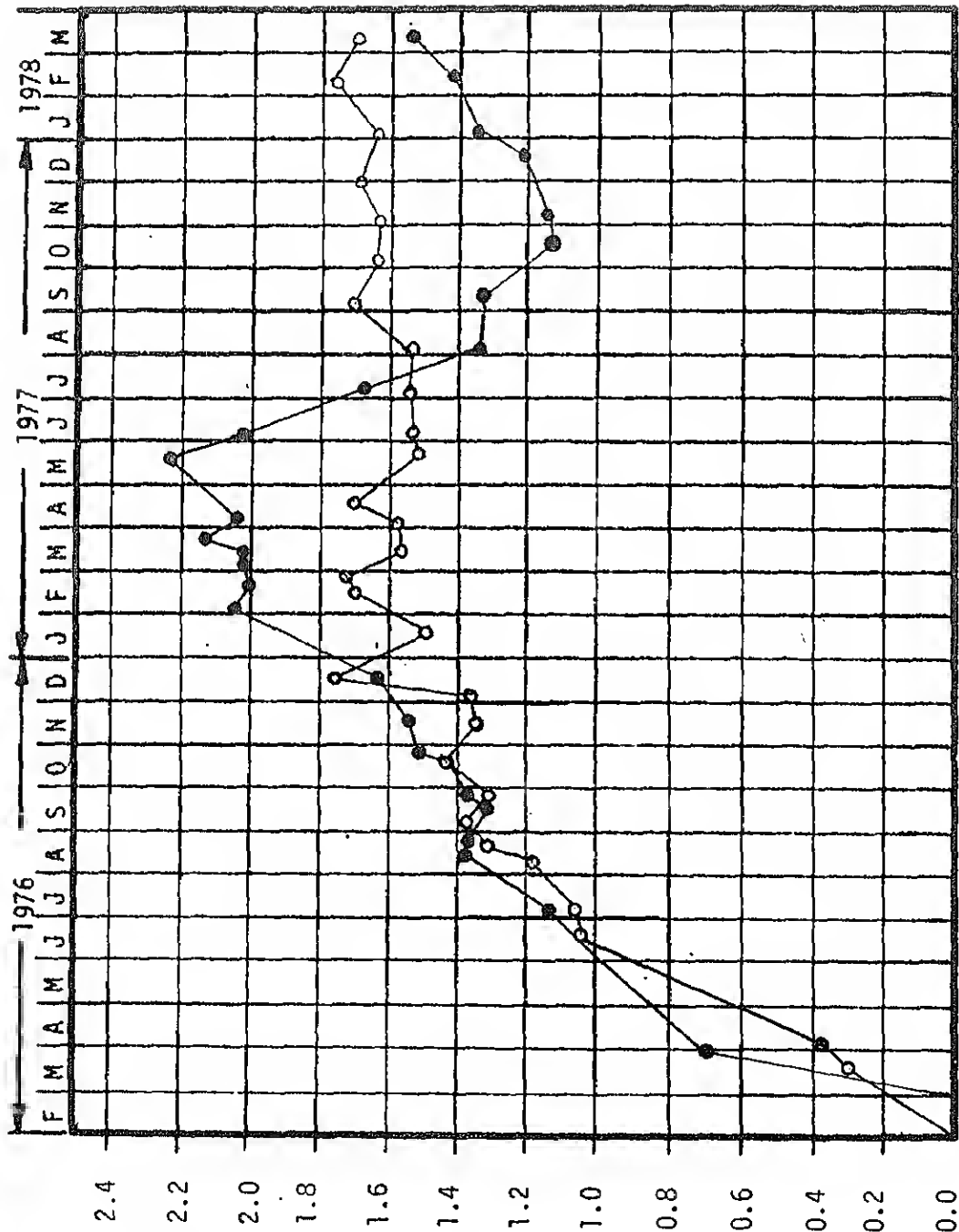
461 Sweetbriar Drive, Lewisville, Texas

Differential Elevation: Lot

te	North Side			East Side			South Side			West Side	
	Ft.	In.	Cm.	Ft.	In.	Cm.	Ft.	In.	Cm.	Ft.	In.
18-76	.019	.228	.579	.019	.228	.579	.005	.060	.152	.022	.264
25-76	.107	1.284	3.261	.020	.240	.610	.009	.096	.244	.087	1.044
02-76	.030	.360	.914	.024	.288	.732	.007	.084	.213	.013	.156
21-76	.086	1.032	2.621	.043	.516	1.311	.022	.264	.671	.022	.264
09-76	.088	1.056	2.682	.042	.504	1.280	.032	.384	.975	.014	.168
09-76	.089	1.068	2.713	.034	.408	1.036	.045	.540	1.372	.010	.120
23-75	.105	1.260	3.200	.044	.528	1.341	.035	.420	1.067	.020	.240
07-75	.113	1.356	3.444	.045	.540	1.372	.048	.576	1.463	.023	.276
29-75	.109	1.308	3.322	.043	.516	1.311	.055	.660	1.676	.011	.132
21-75	.119	1.428	3.627	.048	.576	1.463	.060	.720	1.829	.011	.132
16-75	.081	.972	2.469	.052	.624	1.585	.070	.840	2.134	.013	.156
02-76	.091	1.092	2.774	.048	.576	1.463	.066	.792	2.012	.015	.180
21-77	.119	1.428	3.327	.044	.528	1.341	.067	.804	2.042	.013	.156
18-77	.132	1.584	4.023	.053	.636	1.615	.075	.900	2.286	.015	.180
28-77	.140	1.680	4.267	.048	.576	1.463	.081	.972	2.469	.016	.192
14-77	.123	1.476	3.749	.051	.612	1.554	.074	.888	2.256	.006	.072
04-77	.121	1.452	3.688	.052	.624	1.585	.071	.852	2.164	.013	.156
19-77	.123	1.476	3.749	.052	.624	1.585	.079	.948	2.408	.108	.216
24-77	.103	1.236	3.139	.050	.600	1.524	.077	.924	2.347	.015	.180
10-77	.100	1.200	3.048	.051	.612	1.554	.078	.936	2.377	.020	.240
08-77	.084	1.008	2.560	.055	.660	1.676	.079	.948	2.408	.031	.382
05-77	.096	1.152	2.926	.049	.588	1.494	.080	.960	2.438	.020	.240
07-77	.112	1.464	3.719	.041	.492	1.250	.070	.840	2.134	.014	.168
10-77	.098	1.176	2.987	.054	.648	1.646	.066	.792	2.012	.016	.192
02-77	.110	1.320	3.353	.049	.588	1.494	.078	.936	2.377	.009	.108
01-77	.107	1.284	3.261	.054	.648	1.646	.077	.924	2.347	.011	.132
04-78	.096	1.152	2.926	.055	.660	1.676	.079	.948	2.408	.012	.144

te	North Side			East Side			South Side			West Side		
	Ft.	In.	Cm.	Ft.	In.	Cm.	Ft.	In.	Cm.	Ft.	In.	Cm.
31-77	.045	.540	1.372	.033	.396	1.006	.048	.576	1.463	.037	.446	1.161
02-76	.103	1.236	3.139	.076	.912	2.320	.085	1.020	2.591	.071	.852	2.202
05-76	.081	.972	2.469	.039	.468	1.189	.043	.516	1.311	.074	.888	2.255
13-76	.112	1.344	3.414	.077	.924	2.347	.089	1.068	2.713	.085	1.020	2.602
26-76	.084	1.008	2.560	.072	.864	2.195	.088	1.056	2.682	.081	.972	2.500
14-76	.110	1.320	3.353	.069	.828	2.103	.066	.792	2.012	.070	.840	2.159
30-76	.144	1.368	3.475	.071	.852	2.164	.077	.924	2.347	.081	.972	2.413
22-76	.118	1.416	3.597	.078	.936	2.377	.080	.960	2.438	.079	.948	2.391
26-76	.126	1.512	3.840	.074	.888	2.256	.083	.996	2.530	.097	1.166	2.947
18-76	.130	1.560	3.962	.075	.900	2.286	.089	1.068	2.713	.104	1.248	3.178
21-76	.136	1.632	4.145	.089	1.068	2.713	.100	1.200	3.048	.100	1.200	3.048
07-77	.145	1.740	4.420	.110	1.320	3.353	.110	1.320	3.353	.084	1.008	2.616
21-77	.145	1.740	4.420	.105	1.260	3.200	.117	1.404	3.566	.092	1.104	2.813
04-77	.140	1.680	4.267	.093	1.116	2.835	.123	1.476	3.749	.094	1.128	2.875
14-77	.151	1.812	4.602	.105	1.260	3.200	.123	1.476	3.749	.105	1.260	3.191
11-77	.154	1.848	4.694	.111	1.332	3.383	.122	1.464	3.719	.104	1.248	3.129
23-77	.162	1.944	4.938	.119	1.428	3.627	.132	1.584	4.023	.107	1.284	3.203
09-77	.150	1.800	4.572	.114	1.368	3.475	.118	1.416	3.597	.099	1.188	3.015
12-77	.136	1.632	4.145	.094	1.128	2.865	.101	1.212	3.078	.097	1.164	2.951
11-77	.111	1.332	3.383	.073	.876	2.225	.086	1.032	2.621	.086	1.032	2.621
15-76	.110	1.320	3.353	.072	.864	2.195	.083	.996	2.530	.095	1.140	2.927
21-77	.093	1.116	2.835	.058	.696	1.768	.077	.924	2.347	.096	1.152	2.927
11-77	.098	1.176	2.987	.056	.672	1.707	.064	.768	1.951	.096	1.152	2.927
20-77	.102	1.224	3.109	.052	.624	1.585	.063	.756	1.920	.101	1.212	3.080
05-78	.097	1.164	2.957	.052	.624	1.585	.062	.744	1.890	.097	1.164	2.927
3-78	.118	1.416	3.597	.061	.732	1.859	.058	.696	1.768	.107	1.283	3.203
0-78	.130	1.560	3.962	.082	.984	2.499	.080	.960	2.438	.106	1.272	3.178





# Maximum Perimeter Differential Movement

Date	Movement		
	Feet	Inches	Cm.
Mar. 18, 1976	.024	.288	.732
Mar. 25, 1976	-	-	-
Apr. 2, 1976	.032	.384	.975
June 21, 1976	.086	1.032	2.621
July 9, 1976	.088	1.056	2.682
Aug. 9, 1976	.099	1.188	3.018
Aug. 23, 1976	.109	1.308	3.322
Sep. 7, 1976	.116	1.392	3.536
Sep. 29, 1976	.109	1.308	3.322
Oct. 21, 1976	.119	1.428	3.627
Nov. 16, 1976	.112	1.344	3.414
Dec. 2, 1976	.114	1.368	3.475
Jan. 21, 1977	.124	1.488	3.780
Feb. 18, 1977	.143	1.716	4.359
Feb. 28, 1977	.144	1.728	4.389
Mar. 14, 1977	.131	1.572	3.993
Apr. 4, 1977	.133	1.596	4.054
Apr. 19, 1977	.143	1.716	4.359
May 24, 1977	.127	1.524	3.871
June 10, 1977	.129	1.548	3.932
July 8, 1977	.130	1.560	3.962
Aug. 5, 1977	.129	1.548	3.932
Sep. 7, 1977	.143	1.716	4.359
Oct. 10, 1977	.136	1.632	4.145
Nov. 2, 1977	.136	1.632	4.145
Dec. 1, 1977	.140	1.680	4.267
Jan. 4, 1978	.137	1.644	4.176

Date	Movement		
	Feet	Inches	Cm.
Mar. 31, 1976	.058	.696	1.768
June 2, 1976	.117	1.404	3.566
July 5, 1976	.094	1.128	2.865
Aug. 13, 1976	.116	1.392	3.536
Aug. 26, 1976	.114	1.368	3.475
Sep. 14, 1976	.110	1.320	3.353
Sep. 30, 1976	.114	1.368	3.475
Oct. 22, 1976	.119	1.428	3.627
Oct. 26, 1976	.126	1.512	3.840
Nov. 18, 1976	.130	1.560	3.962
Dec. 21, 1976	.136	1.632	4.145
Feb. 7, 1977	.171	2.052	5.212
Feb. 21, 1977	.167	2.004	5.090
Mar. 4, 1977	.169	2.028	5.151
Mar. 14, 1977	.169	2.028	5.151
Mar. 25, 1977	.180	2.160	5.486
Apr. 11, 1977	.172	2.064	5.243
May 23, 1977	.187	2.244	5.700
June 9, 1977	.169	2.028	5.151
July 12, 1977	.140	1.680	4.267
Aug. 11, 1977	.111	1.332	3.333
Sep. 15, 1977	.110	1.320	3.353
Oct. 21, 1977	.096	1.152	2.926
Nov. 11, 1977	.098	1.176	2.987
Dec. 20, 1977	.102	1.224	3.109
Jan. 5, 1978	.097	1.164	2.957
Feb. 13, 1978	.118	1.416	3.597
Mar. 10, 1978	.130	1.560	3.962
Apr. 3, 1978	.132	1.580	4.023
May 15, 1978	.122	1.512	3.840

occurs well above the average Plastic Limit of the soil which was determined to be 22.4 percent in the upper five feet of soil.

The average natural moisture content of the foundation subsoil at this location on the Eagle Ford formation was 18.28 percent to a five foot depth. The standard deviation of natural moisture below the Plastic Limit was 13.7 percent above the Plastic Limit, approximately 8,381 gallons of water were added to the subsoil. Figure 34, shows the moisture contents at the house at all depths of interest.

An abrupt variation was noted in data values for moisture contents, especially in the upper soil depths. It was anticipated this would occur in the first few months after water was added to the subsoil while diffusion was taking place. Abrupt changes beyond that point in time were considered errors by research personnel in reading instrument values. Significant fluctuation in the moisture cell on the West side of the house began in 1977, and decreased down to a value of 15 percent. This instrument was re-evaluated, but it would appear that failure has occurred. In most cases, the variations occurring in soil moisture as given in Figure 34 are well above the desired minimum of approximately 25 percent.

The variation of soil temperature at all depths of interest, varying with time, is given in Figure 35. These curves show the desired characteristic shape, with amplitude decreasing with soil depth. The values of the test data did not indicate any influence of the climatic cycle, and the performance of soil as an insulating medium. The values of the means and deviations are given in Table 19.

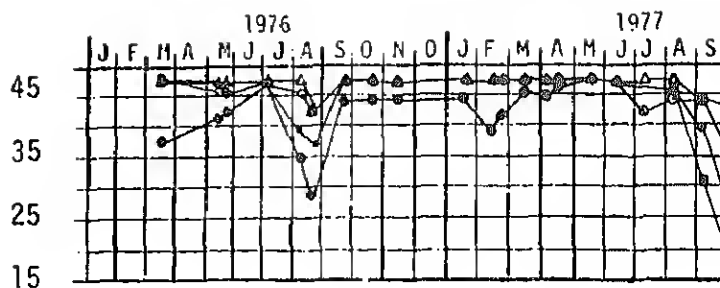
#### Soil Moisture-Temperature Characteristics - 1314 Athens Street, Mesquite, Texas

The acquisition for variation in soil moisture content with time, as shown in Figure 36, commenced upon completing all tasks associated with the rubber moisture barrier as a subsoil stabilization technique. The variation with time is noted in the upper depths of interest, the test occurs well above the average Plastic Limit of the soil which was determined to be 22.4 percent in the upper five feet of soil.

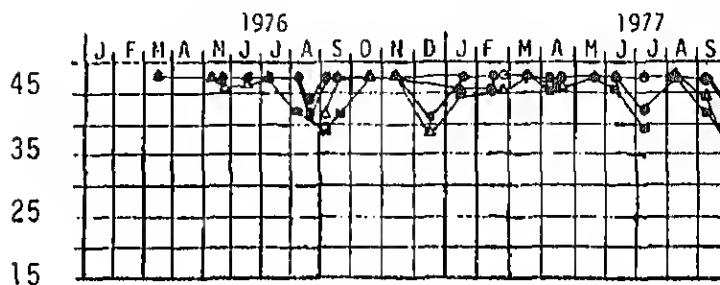
The average natural moisture content of the foundation subsoil at this location on the Taylor formation was 20.68 percent to a five feet depth. The standard deviation of natural moisture below the Plastic Limit was 8.5 percent. To raise the moisture content of the subsoils a minimum of 2-3 percent above the average Plastic Limit, approximately 15,610 gallons of water were added. This increase in water volume was 1.86 times the amount of water added to the test house soils, using the same subsoil stabilization technique, on the Eagle Ford formation. This increased volume of water was added to bring the moisture content of the subsoil in the upper five feet

↑  
MOISTURE CONTENT (%)

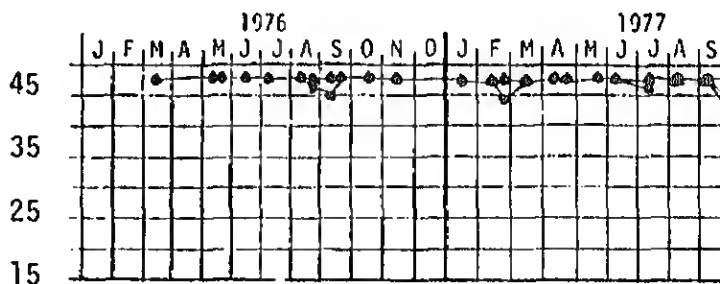
\*Depth 1



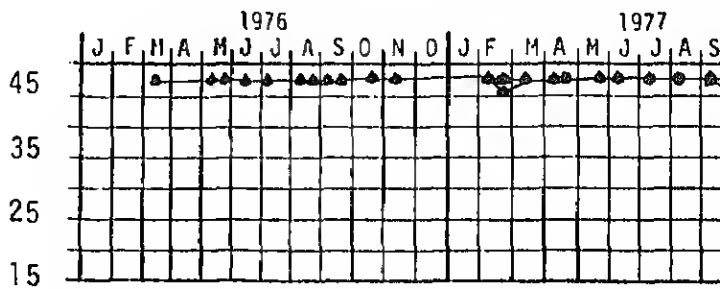
Depth 2.5



Depth 4

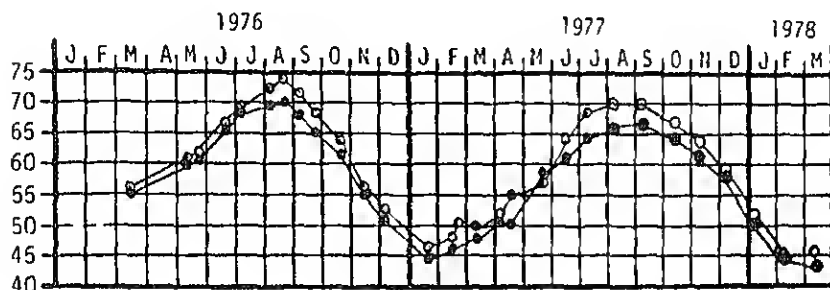


Depth 5.5

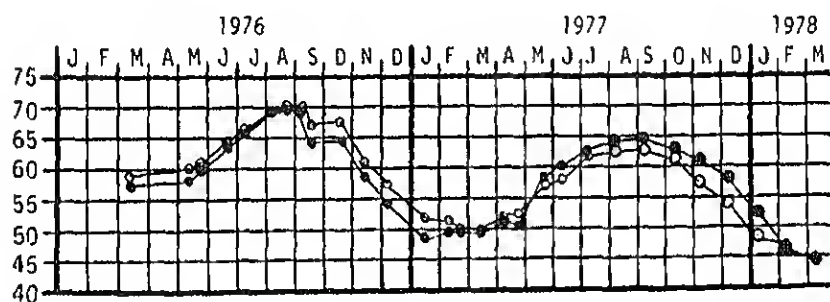




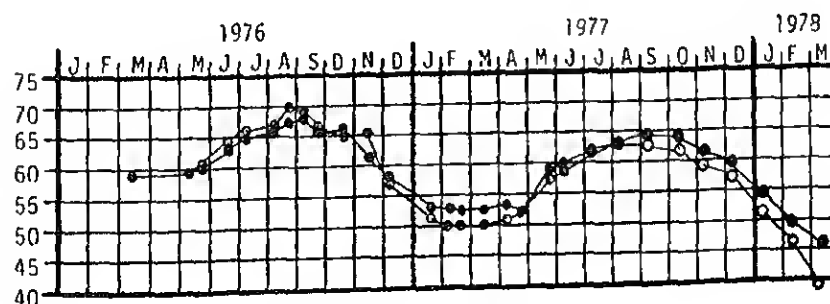
h 2.5



h 4



h 5.5



-Key-

- North and South Side Average
- East and West Side Average

ths refer to feet below grade beam.

Table 19

## TEMPERATURE MEANS AND STANDARD DEVIATION

11 Sweetbriar Drive, Lewisville, TX

Rubber Barrier-Water

Location	*Depth (ft)		
	1	2.5	4
	61.53	59.00	59.47
	10.46	8.98	6.84
	57.35	57.94	59.21
	9.41	8.52	7.55
	57.69	62.95	60.00
	9.59	9.10	7.28
	59.24	60.61	58.47
	9.87	8.23	6.99

5.5

58.16  
7.5759.53  
5.9860.45  
6.4859.79  
6.08

Table 20

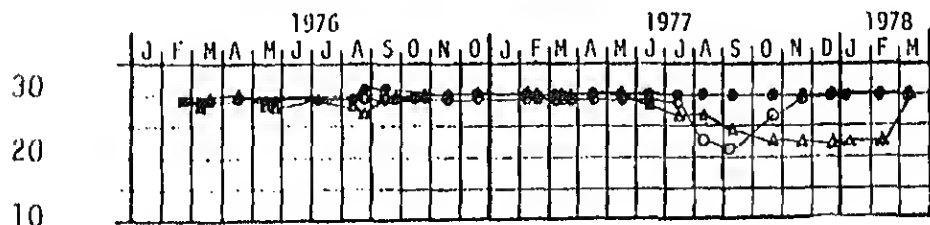
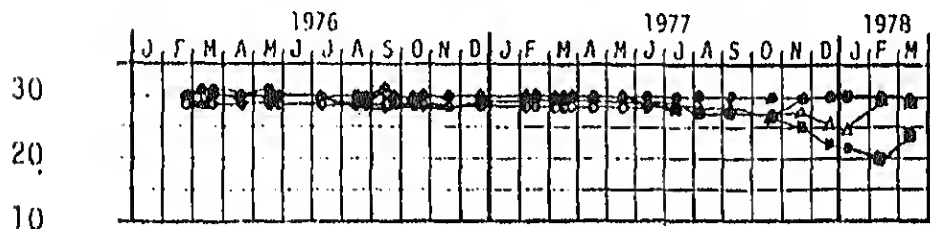
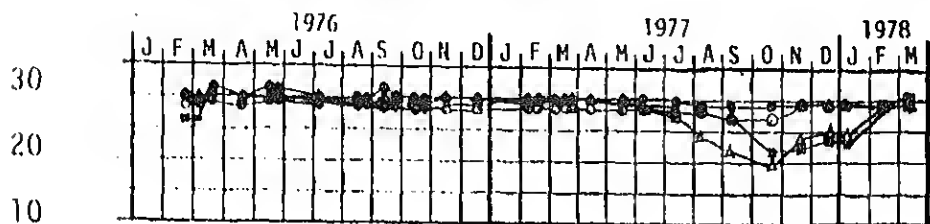
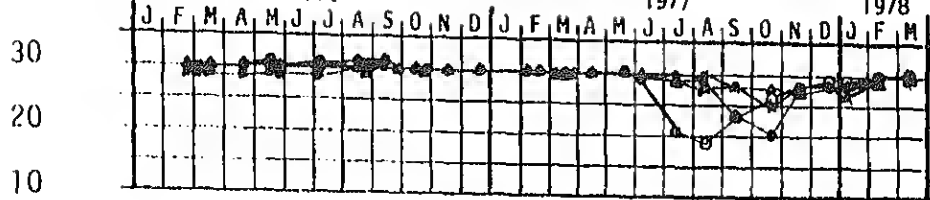
## TEMPERATURE MEANS AND STANDARD DEVIATION

1314 Athens Street, Mesquite,

Rubber Barrier-Water

Location	*Depth (ft)		
	1	2.5	4
North	61.36	58.05	60.73
	10.50	8.13	8.30
East	58.55	60.82	57.91
	9.29	8.66	7.90
South	62.30	63.18	59.98
	8.24	8.92	7.07
West	60.00	61.00	dead
	9.18	7.06	

\* Depth refers to feet below grade beam.



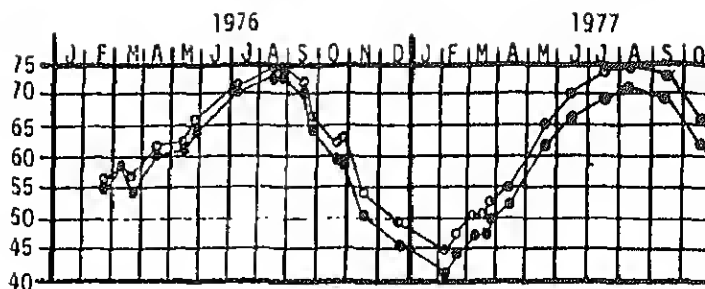
- North Side Boring
- East Side Boring
- △ South Side Boring
- West Side Boring

\* Refers to Depths Below Perimeter Grade Beam  
 Fig. 36 Soil Moisture Content - Rubber Barrier  
 1314 Athens Street, Mesquite, Texas

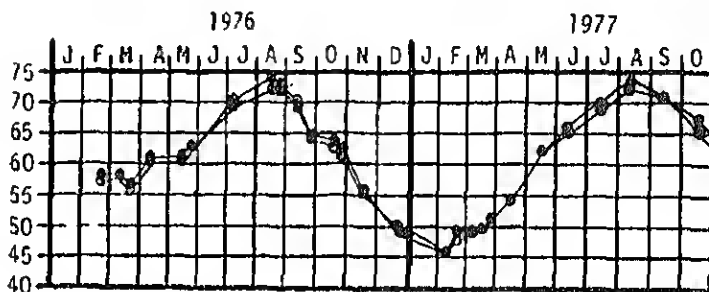


Soil Temperature ( $^{\circ}$  F)

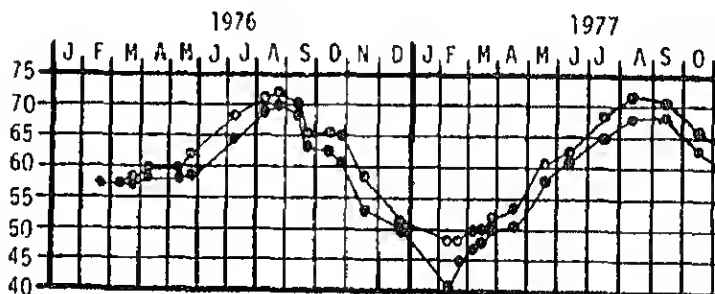
\*Depth 1



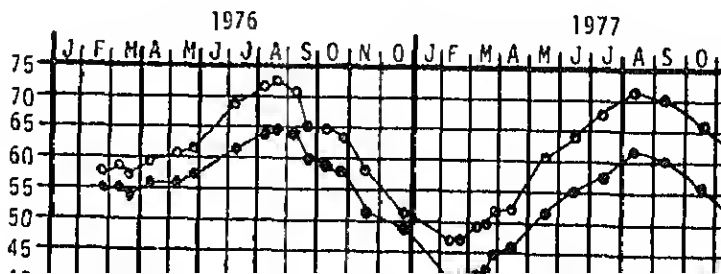
Depth 2.5



Depth 4



Depth 5.5



is submitted that an undetermined volume of the added water was lost to significant depths in the subsoil and also to soil outside the rubber barrier by the ready avenues of escape provided by fractures and cracks in the formation subsoil. As the soil expanded and gradually restricted these flow paths, the increase in soil moisture was obtained in the soil mass surrounded by the rubber barrier.

The variation of the soil temperature with time and for different depths is given in Figure 37. These curves show the characteristic sine wave shape and amplitude change with depth, and for this test house, more variation in temperature was noted at the lower depths in the subsoil. This can be explained by referring to Table 20, page 76, which gives the temperature means and standard deviations for the test house on the Taylor formation. It can be noted that no data is given for depths 4 and 5.5 for the soil boring on the West side of the test house. The thermistor portion of the moisture-temperature cell installed at these two depths became inoperative a short time subsequent to installation. Consequently, the curves plotted in Figure 37 indicate average temperatures for the North and South sides of the test house, but only the East side temperature readings are plotted for depths 4 and 5.5. In this area, the East side would be protected from climatic variations much more so than the West side and consequently cooler.

#### 4.3.6 Comparison of Soil Moisture-Temperature Characteristics

The test house at 461 Sweetbriar Drive, Lewisville, Texas, was situated on the residual expansive clays of the Eagle Ford formation. From the soil investigation for this test house, it was established that the insitu natural subsoil properties prior to installation of the stabilization technique included an average Plastic Limit of 22.4 percent within the upper five feet. Further, the average natural moisture content of the subsoil to the same depth was 18.28 percent. The maximum deviation of the subsoil moisture content below the Plastic Limit was approximately 13.7 percent.

The test house at 1314 Athens Street, Mesquite, Texas was located on the residual soils of the Taylor formation, which is also quite expansive. From the soils investigation for this test house, the insitu average natural moisture content was 20.68 percent within the upper five feet. The maximum deviation below the Plastic Limit was approximately 8.5 percent. These properties were determined prior to initiating any actions associated with subsoil stabilization.

The average Plastic Limit of the subsoils beneath the two houses are similar, 22.4 percent and 22 percent respectively. The natural insitu moisture content of the subsoil for the house on the Eagle Ford formation and for the house on the Taylor formation vary by approximately 2.4 percent, not a significant variation for differences in magnitude of monitored moisture content. It was found that

Use two test locations, a reversal of index properties was noted. The natural moisture content of the Taylor formation was higher and there was significantly less deviation in the moisture content below the Plastic Limit for the house on the Eagle Ford formation 8.5 percent as compared to .7 percent, respectively.

For these two test locations it was found that a reversal occurred in the percentage of the highly expansive clay minerals of the Montmorillonite group in the upper five feet. For the test house on the Eagle Ford formation an average of 36 percent of Montmorillonite was evidenced within the depth of interest, while for the test house on the Taylor formation, the average was 24.4 percent, or a difference of approximately 11.6 percent. As both formations are sedimentary deposits associated with the same general geologic time, this was not considered unusual.

The large percentage of Montmorillonite clay minerals within the upper five feet of soil for the test house located on the Eagle Ford formation could result in the significant increase in moisture content within the soil mass encompassed by the relatively impermeable rubber barrier. Even though less water volume was introduced into the subsoil, the significant increase in percentage of Montmorillonite clay minerals with their high specific surface area and affinity for free water would justify the increased moisture content. The lower natural water content of the soil, and the high deviation of the in situ moisture content below the Plastic Limit of the soil would be contributing factors. Consequently, adjustment of the soil moisture contents with time and the aforementioned expansive characteristics would result in increased vertical movement.

For the test house at 1314 Athens Street, Mesquite, Texas, the variation in soil moisture with time as given in Figure 36, page 80, is relatively uniform at all depths of interest. It is reiterated that a much larger volume of water was introduced into the subsoil surrounded by the relatively impermeable rubber barrier. The soils of this formation are dense and fractured and it was believed a significant quantity of water was able to migrate to great depths and outside of the barrier perimeter. Consequently, a much greater mass of soil, also containing a significant percentage of Montmorillonite clay, was able to experience its swell potential.

A comparison of the variations in soil temperature with time from data given in Figures 35 and 37, and Tables 19 and 20, pages 75, 78, 76 and 79, are relatively similar. It may be concluded that both referenced figures would exhibit like variations with depth and time, if the thermistors in the lower soil depths on the West side of the house at 1314 Athens Street, Mesquite, Texas, had not malfunctioned. Soils on the West side of a house in this area are subjected to more intense variation with time and as a consequence, the temperature variations given in Figure 37, page 78, for depths 4 and 5.5 feet reflect North and South side temperature averages for one curve, but only West side temperature data for the second curve at each depth, for this test.

floor plans, trenching, concrete barrier, instrumentation, permanent bench mark, costs, increasing foundation soil investigation have previously been given. In addition, of each floor slab plan prior and subsequent to corrective been reported. (1,2)

### Soil Movement - 1137 Eastwood Drive, Lewisville, Texas

tion of vertical movements around the foundation perimeter after the concrete barrier was in place and the foundation soil increased a minimum of 2-3 percent above the Plastic Limit. 27 gallons of water were added to the subsoil encompassed by barrier. The floor slab at 1137 Eastwood Drive, Lewisville, Texas, was in "U" configuration. The perimeter edges were higher than the slab. Water was added to the subsoil from the interior selected locations through the floor slab depending on elevation.

Figure 20 shows the vertical movements along each side of the test house. The performance period is for approximately two years, or two annual cycles. It was seen that the high point of the perimeter level pin 11 or the Southwest corner of the test house. The low point occurs at level pin 14 or along the East side of the test house. Data are given for January 1978. The uniformity of movement around the perimeter, as indicated by distances between the data points given for each side of the test house is significant. The maximum variation between the high and low points around the perimeter, for the test house is approximately 1.74 inches, and the maximum change in elevation between points is 0.84 inches. The anticipated low point on the perimeter occur at the Southwest corner, and the high point at the North-East corner. The variation in soil properties in the subsoil mass encompassed by the barrier could account for this anomaly. The purpose of the barriers was to mitigate or inhibit subsoil volume changes due to climatic effects.

Figure 21 and Table 21 show absolute differential movements with time around the perimeter of the test house. The similarity of the differential elevations on the South and West sides and the similarity of the curves for the East and North sides is interesting.

Data acquisition of vertical movements for this test house located on residual soils of the Taylor formation was initiated after all actions associated with utilizing a concrete barrier to inhibit moisture migration due to climatic effects were complete. Approximately 13,410 gallons of water were added to the foundation subsoil surrounded by the concrete barrier. This test house floor slab had a "domed" shape and water was introduced into the subsoil by drilling access holes with a masonry drill through the barrier to insert an injection lance. All holes around the perimeter were temporarily sealed after each injection, and permanently sealed after the desired moisture content within the subsoil was established.

Figure 40 shows the vertical movement variation associated with time along each side of the test house. As before, the performance period approximately 2 years, which illustrates the effects of climate over approximately four seasonal cycles. The high point on the perimeter of this test house also occurred at the Southwest corner or level pin 7 and the low point was at level pin 4 on the East side of the house. These data are for January 1978. The uniformity of vertical movement around the perimeter is considered exceptional for this expansive clay soil. The vertical movements can be closely studied from the data points given in Figure 40 for each side of this test house. The maximum change in vertical elevation between leveling pins of 0.36 inches for the month of January 1978. The maximum change in vertical movement between the high and low points around the perimeter of the test house, for the same time period, is approximately 0.78 inch. The small differential movements associated with the lean concrete barrier surrounding the subsoil mass are attributed to variations of the soil properties with the effected volume.

Figure 41 and Table 22 show absolute differential movements with time along each side of the test house. Figure 41 illustrates the increasing stability of the foundation subsoil with time, and also the lack of influence associated with climatic conditions.

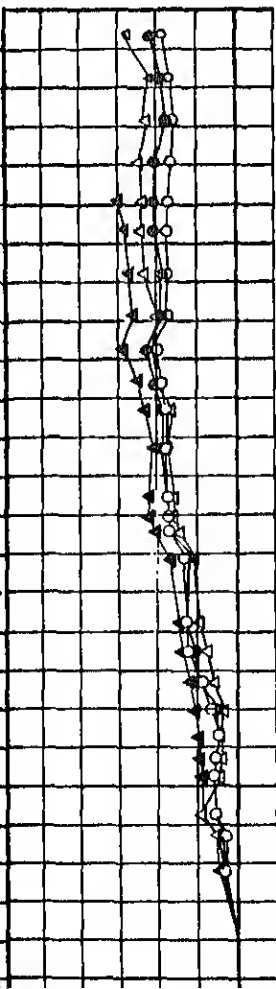
Comparison of Vertical Movements

The maximum vertical movement for the test house at 1137 Eastwood Drive, Lewisville, Texas, is more than double the vertical movements of the test house at 4204 Culmer, Balch Springs, Texas. These data are for January 1978. The same statement is made for absolute differential movements. A comparison of the data given in Figures 38, 39, 40, and 41, pages 83, 84, 85, and 87 justify these statements.

Figure 42 and Tables 23 and 24 were developed by taking the high and low points around the perimeter of each test house and varying these data with time. Consequently, the vertical movements of the test house at 1137 Eastwood Drive, Lewisville, Texas, are compared with the test house at 4204 Culmer, Balch Springs, Texas, for the same time period.

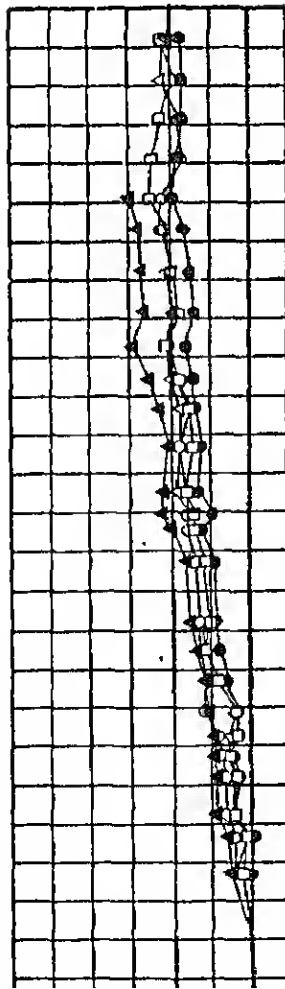
# NORTH SIDE

Level Pin 1 ○  
 Level Pin 2 ●  
 Level Pin 3 ▲  
 Level Pin 4 ▲



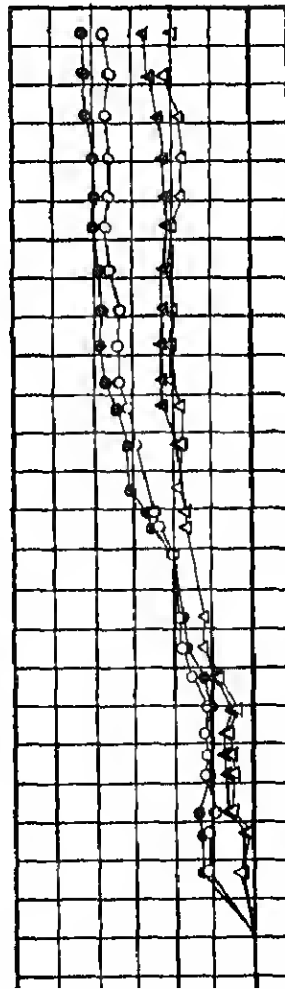
## EAST SIDE

Level Pin 4 ▲  
 Level Pin 5 □  
 Level Pin 6 ○  
 Level Pin 7 ●  
 Level Pin 8 ▲



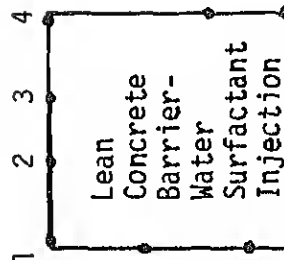
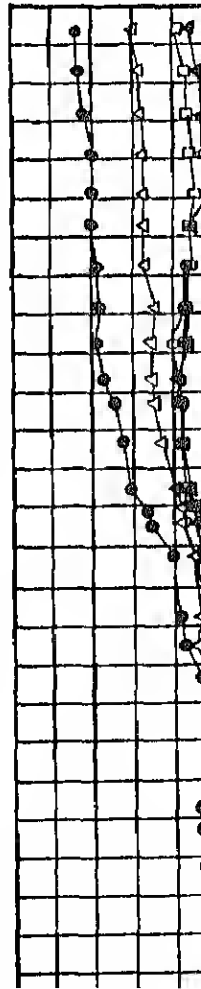
## SOUTH SIDE

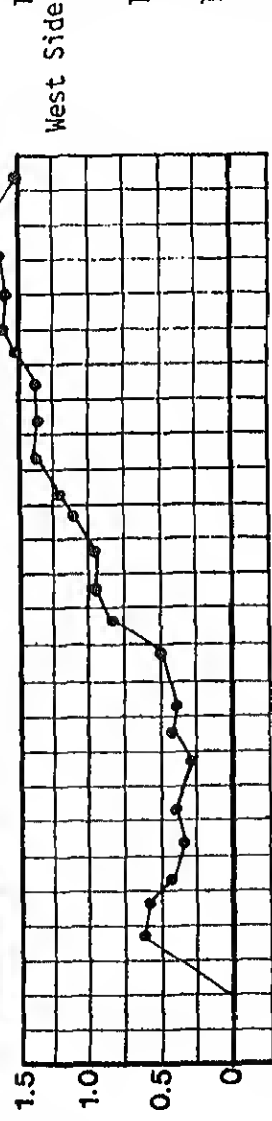
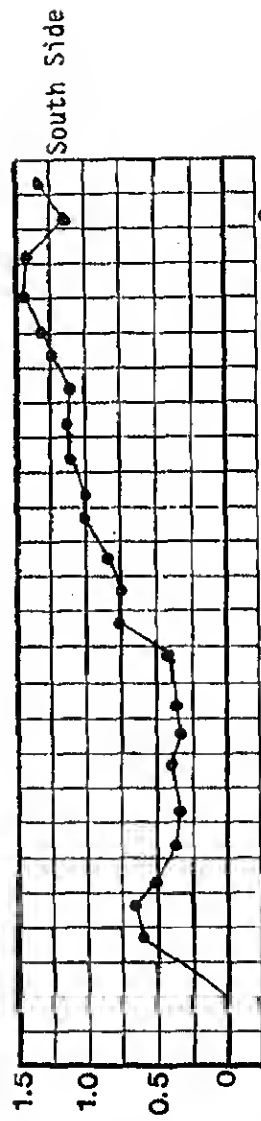
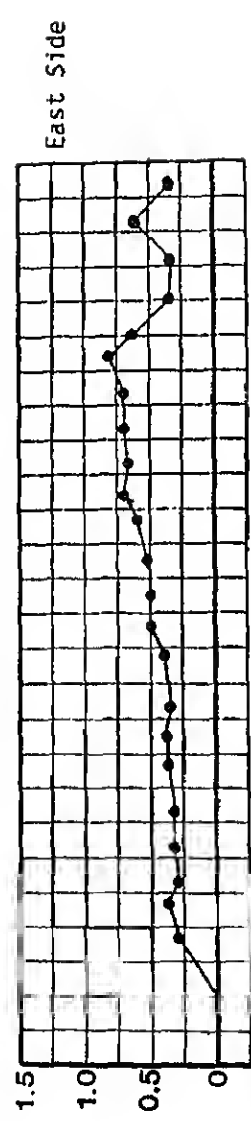
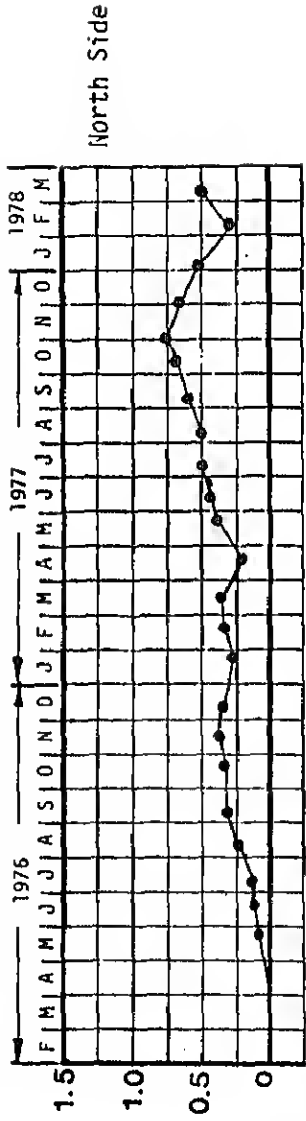
Level Pin 8 ▲  
 Level Pin 9 ▲  
 Level Pin 10 ○  
 Level Pin 11 ●



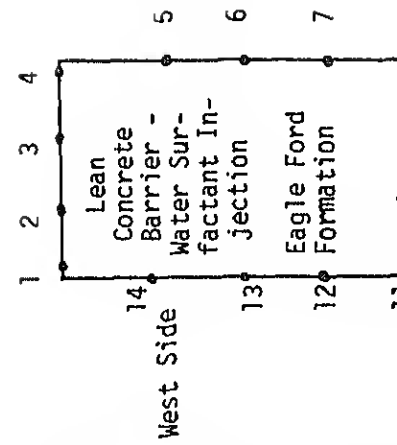
## WEST SIDE

Level Pin 11 ●<sup>14</sup>  
 Level Pin 12 ▲  
 Level Pin 13 □<sup>13</sup>  
 Level Pin 14 ▲<sup>13</sup>  
 Level Pin 1 ○





Change in Elevation (inches) ↑



013	.156	.396	.024	.288	.732	.043	.516	1.311	.038	.456	1.158
020	.240	.610	.026	.312	.792	.031	.372	.945	.027	.324	.823
026	.312	.792	.025	.300	.762	.031	.372	.945	.032	.384	.975
022	.264	.671	.028	.336	.853	.029	.348	.884	.035	.420	1.067
030	.360	.914	.046	.552	1.402	.037	.444	1.128	.023	.276	.701
028	.336	.863	.031	.372	.945	.036	.432	1.097	.024	.288	.732
033	.396	1.006	.033	.396	1.006	.027	.324	.823	.038	.456	1.158
027	.324	.823	.030	.360	.914	.031	.372	.945	.033	.396	1.006
024	.288	.732	.036	.432	1.097	.037	.444	1.128	.043	.516	1.311
028	.336	.853	.041	.492	1.250	.065	.780	1.981	.069	.828	2.103
030	.360	.914	.050	.600	1.524	.050	.600	1.524	.060	.720	1.829
032	.384	.975	.041	.492	1.250	.062	.744	1.890	.079	.948	2.408
019	.228	.579	.044	.520	1.321	.070	.840	2.134	.079	.948	2.408
033	.396	1.006	.049	.588	1.494	.085	1.020	2.591	.092	1.104	2.804
038	.456	1.158	.060	.720	1.829	.083	.996	2.530	.101	1.212	3.078
042	.504	1.280	.057	.684	1.737	.092	1.104	2.804	.115	1.380	3.505
043	.516	1.311	.058	.696	1.768	.095	1.140	2.896	.114	1.360	3.454
051	.612	1.554	.059	.708	1.798	.092	1.104	2.804	.116	1.392	3.536
055	.660	1.676	.065	.780	1.981	.102	1.224	3.109	.130	1.560	3.962
055	.780	1.981	.054	.648	1.646	.111	1.332	3.383	.145	1.740	4.420
053	.636	1.615	.030	.360	.914	.120	1.440	3.658	.141	1.692	4.298
043	.516	1.311	.028	.336	.853	.116	1.392	3.536	.149	1.788	4.542
026	.312	.792	.048	.576	1.463	.099	1.188	3.018	.144	1.728	4.389
043	.516	1.311	.030	.360	.914	.111	1.332	3.383	.129	1.548	3.932



1976

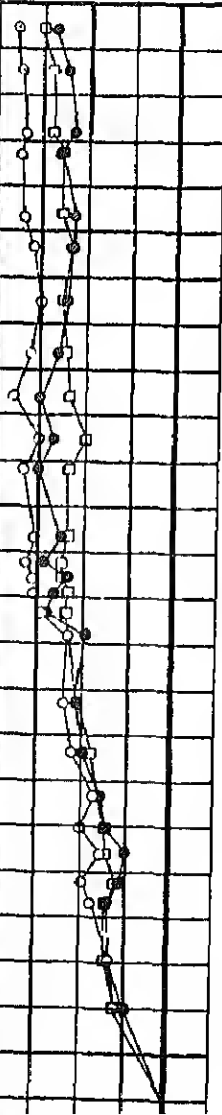
1977

1978

A M J J A S O N D J F M A M J J A S O N D J F M

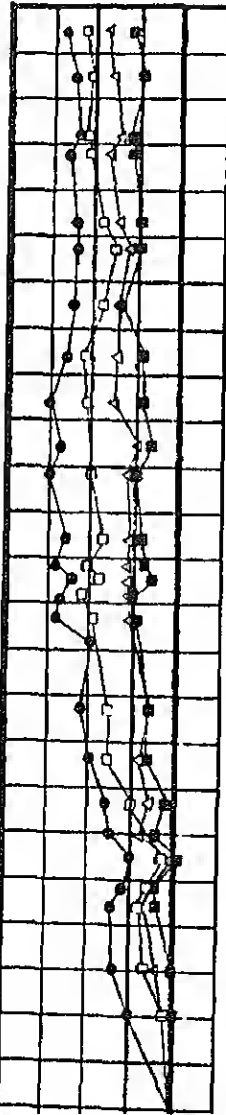
# NORTH SIDE

Level Pin 1 ○  
Level Pin 2 ●  
Level Pin 2 □



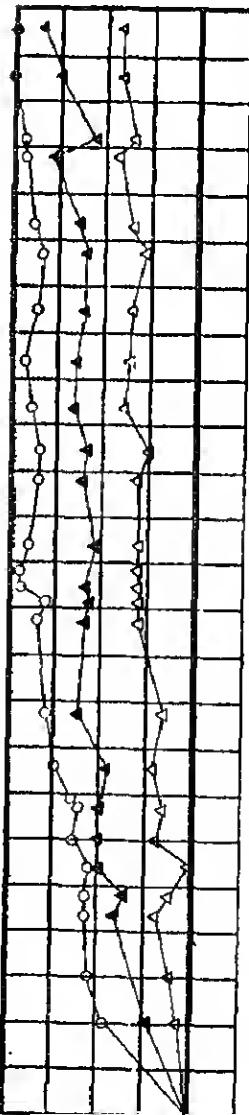
# EAST SIDE

Level Pin 2 ●  
Level Pin 3 □  
Level Pin 4 ▲  
Level Pin 5 △



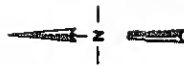
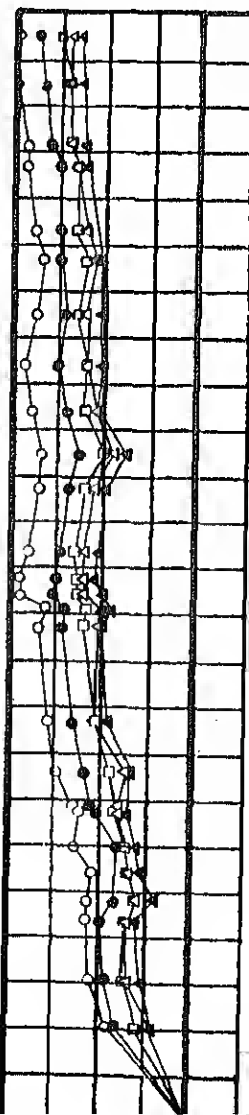
# SOUTH SIDE

Level Pin 5 △  
Level Pin 6 ▲  
Level Pin 7 ○



# WEST SIDE

Level Pin 7 ○  
Level Pin 8 ●  
Level Pin 9 ▲  
Level Pin 10 △  
Level Pin 11 □



1  
Lean Con  
Barrier  
Water-  
Surface  
Injection

11

10

9

8

Taylor M  
Format

7

6

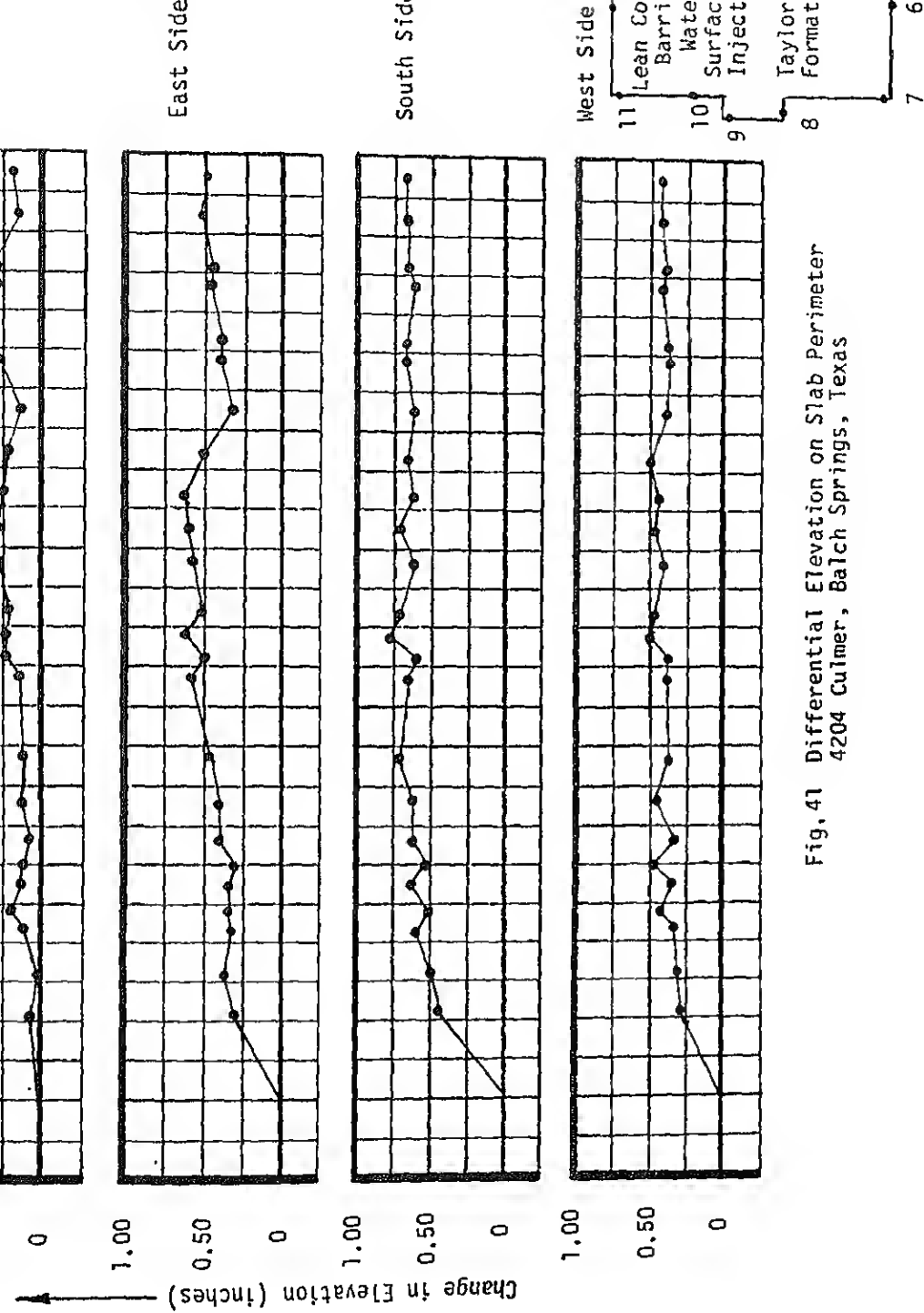


Fig. 41 Differential Elevation on Slab Perimeter  
4204 Culmer, Balch Springs, Texas

Table 22  
4204 Culmer, Balch Springs, Texas

Differential Elevation: Lot

Date	North Side			East Side			South Side			West Side	
	Ft.	In.	Cm.	Ft.	In.	Cm.	Ft.	In.	Cm.	Ft.	In.
5-02-76	.006	.072	.183	.026	.312	.792	.038	.456	1.158	.023	.276
7-02-76	.002	.024	.061	.034	.408	1.036	.070	.840	2.134	.025	.300
8-13-76	.009	.108	.274	.027	.324	.823	.049	.588	1.494	.027	.324
8-26-76	.018	.216	.549	.029	.348	.884	.043	.516	1.311	.037	.446
9-14-76	.013	.156	.396	.229	.348	.884	.054	.648	1.646	.028	.336
9-30-76	.012	.144	.366	.036	.312	.792	.045	.540	1.372	.041	.492
10-22-76	.007	.084	.213	.035	.420	1.067	.046	.552	1.402	.025	.300
10-26-76	.009	.108	.274	.035	.420	1.067	.052	.624	1.585	.027	.324
11-18-76	.012	.144	.366	.035	.420	1.067	.052	.624	1.585	.037	.444
12-21-76	.010	.120	.305	.040	.480	1.219	.062	.744	1.890	.031	.372
12-22-77	.014	.168	.427	.040	.588	1.494	.056	.672	1.707	.034	.408
1-04-77	.020	.240	.610	.041	.492	1.250	.051	.612	1.554	.033	.396
1-14-77	.017	.204	.518	.047	.564	1.433	.064	.768	1.951	.043	.516
1-25-77	.020	.240	.610	.055	.660	1.676	.065	.780	1.981	.040	.480
4-11-77	.018	.216	.549	.044	.528	1.341	.061	.732	1.859	.039	.468
5-23-77	.024	.288	.732	.049	.588	1.494	.052	.624	1.585	.036	.432
5-14-77	.023	.276	.701	.051	.612	1.554	.061	.732	1.859	.040	.480
7-12-77	.029	.348	.884	.054	.648	1.646	.052	.624	1.585	.037	.444
8-11-77	.019	.228	.579	.044	.528	1.341	.057	.684	1.737	.041	.492
9-15-77	.013	.156	.396	.028	.336	.853	.052	.624	1.585	.034	.408
10-21-77	.023	.276	.701	.034	.408	1.036	.056	.672	1.707	.032	.384
11-11-77	.029	.348	.884	.033	.396	1.006	.055	.660	1.676	.033	.396
12-20-77	.023	.276	.701	.038	.456	1.158	.051	.612	1.554	.035	.420
1-05-78	.026	.312	.792	.032	.384	.975	.059	.708	1.798	.034	.408
2-13-78	.017	.204	.518	.044	.528	1.341	.059	.708	1.798	.038	.456
3-10-78	.020	.240	.610	.041	.492	1.250	.059	.708	1.798	.038	.456

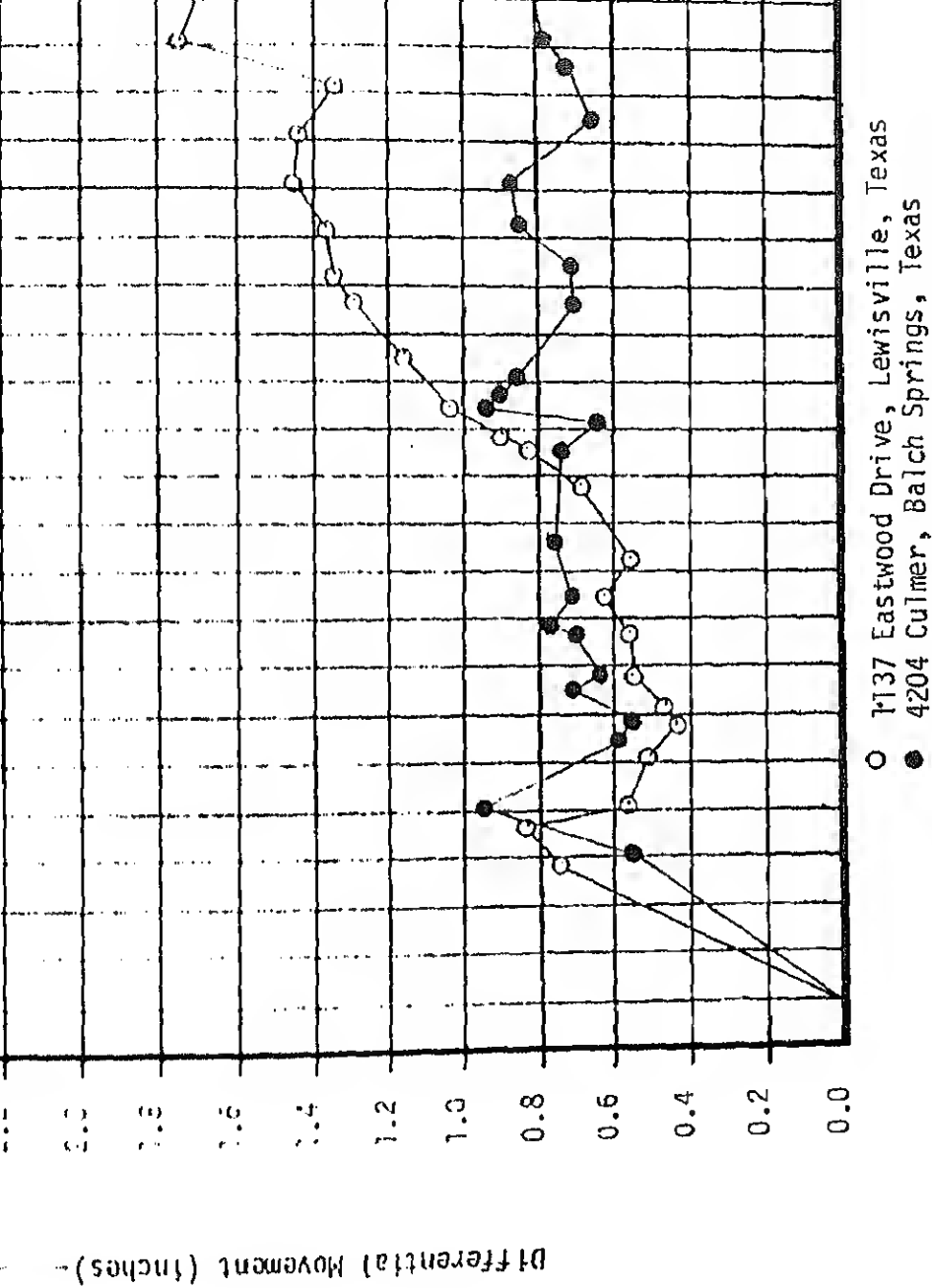


Fig. 42 Maximum Perimeter Differential Movement Comparison of Culm on Different Geologic Formations.

Date	Movement		
	Feet	Inches	
May 25, 1976	.062	.744	1.
June 21, 1976	.068	.816	2.
July 9, 1976	.048	.576	1.
Aug. 9, 1976	.040	.480	1.
Aug. 23, 1976	.036	.432	1.
Sep. 9, 1976	.039	.468	1.
Sep. 29, 1976	.046	.552	1.
Oct. 21, 1976	.046	.552	1.
Nov. 16, 1976	.051	.612	1.
Dec. 9, 1976	.046	.552	1.
Jan. 27, 1977	.057	.684	1.
Feb. 18, 1977	.069	.828	2.
Feb. 28, 1977	.076	.912	2.
Mar. 14, 1977	.086	1.032	2.
Apr. 19, 1977	.098	1.176	2.
May 24, 1977	.107	1.284	3.
June 10, 1977	.114	1.368	3.
July 8, 1977	.115	1.380	3.
Aug. 5, 1977	.121	1.452	3.
Sep. 7, 1977	.119	1.428	3.
Oct. 10, 1977	.112	1.344	3.
Nov. 2, 1977	.145	1.740	4.
Dec. 1, 1977	.141	1.691	4.
Jan. 4, 1978	.149	1.7881	4.
Feb. 6, 1978	.147	1.764	4.
Mar. 8, 1978	.132	1.584	4.
Apr. 3, 1978	.14	1.68	4.
May 15, 1978	.147	1.764	4.

Date	Movement		
	Feet	Inches	Cm.
2, 1976	.045	.540	1.372
7, 1976	.079	.948	2.408
13, 1976	.049	.588	1.494
26, 1976	.047	.564	1.433
14, 1976	.059	.708	1.798
30, 1976	.052	.624	1.585
22, 1976	.057	.684	1.737
26, 1976	.062	.744	1.890
18, 1976	.058	.696	1.768
21, 1976	.063	.756	1.920
7, 1977	-	-	-
22, 1977	.061	.732	1.859
4, 1977	.052	.624	1.585
14, 1977	.078	.936	2.377
25, 1977	.076	.912	2.316
11, 1977	.070	.840	2.134
23, 1977	.058	.696	1.768
14, 1977	.059	.708	1.798
12, 1977	.070	.840	2.134
11, 1977	.071	.852	2.164
15, 1977	.053	.636	1.615
21, 1977	.060	.720	1.829
11, 1977	.066	.792	2.012
20, 1977	.067	.804	2.042
5, 1977	.069	.828	2.103
13, 1978	.077	.924	2.347
10, 1978	.074	.888	2.256
3, 1978	.079	.948	2.408

In both instances, the subsoil mass was enclosed by a relatively impermeable concrete barrier, inhibiting climatic effects. The data given indicates activity within the soil mass in adjusting to stability. Significant deviation or abrupt changes from a smooth curve was considered an indication of expansive clay activity. Further, as data points appeared to be approaching or becoming asymptotic to a horizontal plane would indicate the subsoil mass beneath each test house was reaching relative stability.

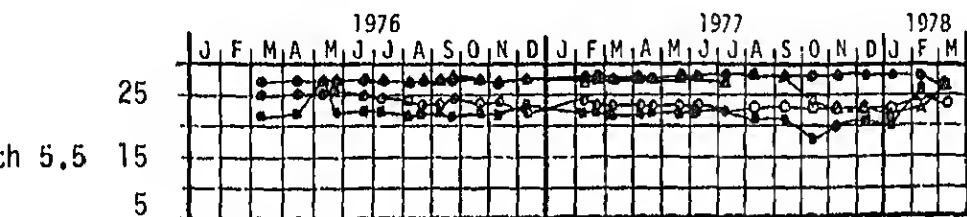
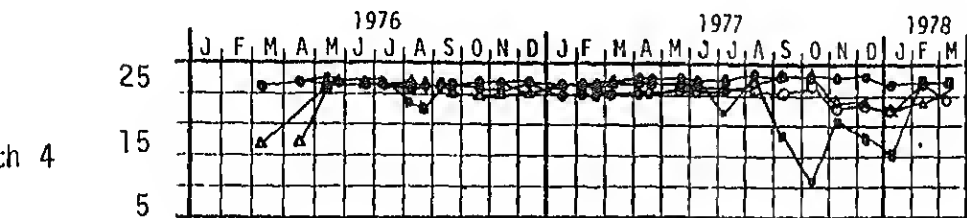
Figure 42 illustrates this concept and shows the soil mass beneath the test house on the Taylor formation surrounded by a vertical concrete barrier to be approaching relative stability. The test house founded on the Eagle formation is still undergoing significant swelling as indicated by the slope of the data points.

#### 4.4 Soil Moisture-Temperature Characteristics - 1137 Eastwood Drive, Lewisville, Texas

Data acquisition for variation in soil moisture content with time, as given in Figure 43, commenced upon completing all tasks associated with utilizing the lean concrete barrier as a subsoil stabilization technique. Significant variation was noted in moisture contents as a function of time at all depths of interest.

The average Plastic Limit in the upper five feet of the soil at this test house was 24.75 percent. As indicated by Figure 43, the minimum requirement for the soil moisture to be a minimum of 2-3 percent above the Plastic Limit was not achieved for certain depths and different sides of the house. While some reading error is apparent in certain instances, the moisture content as taken from the moisture-temperature cells was not increased to the desired level.

As given in Section 4.4.1, 9,827 gallons of water were added to the soils beneath the floor slab and surrounded by the concrete barrier. Further, the entire volume of water was added to the soil from the interior of the house. The floor slab had a "cupped" configuration, and borings were made through the slab on the interior of the house governed by the high and low points determined by topographical survey. Further, testing of the soils in the upper five feet to determine whether or not the moisture content was increased to the minimum desired was also accomplished at the access points from the interior of the house. The moisture-temperature cells are installed in borings approximately 12-18 inches from the house perimeter which may result in the moisture gradient decreasing and recording less than the optimum of the instruments. If the preceding was the case, it is then possible that the installed instruments and the insitu soil do not have completely intimate contact resulting in readings that are less than desirable. The mass of soil enclosed by the vertical concrete barrier could have different moisture contents throughout and particularly have higher moisture contents at the in-



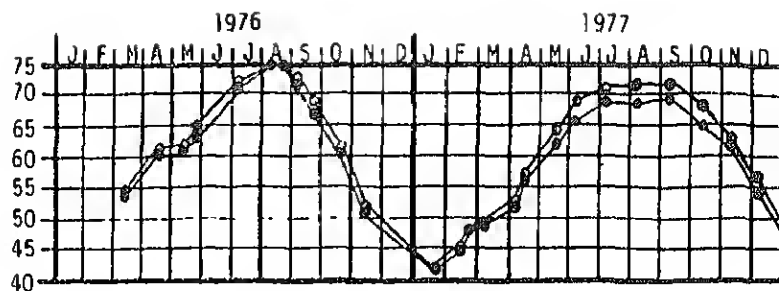
- North Side Boring
- East Side Boring
- △ South Side Boring
- West Side Boring

\* Refers to Depths Below Perimeter Grade Beam

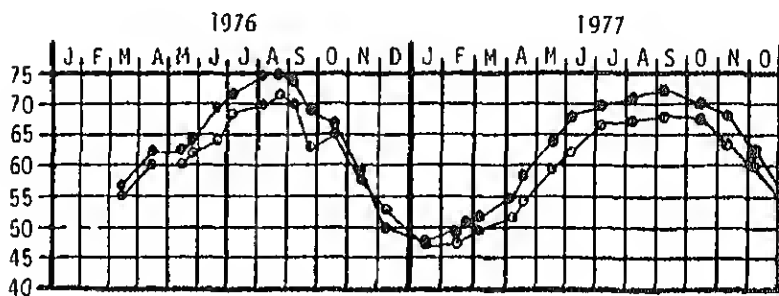
Fig. 43 Soil Moisture Content - Lean Concrete Barrier  
1137 Eastwood Drive, Lewisville, Texas



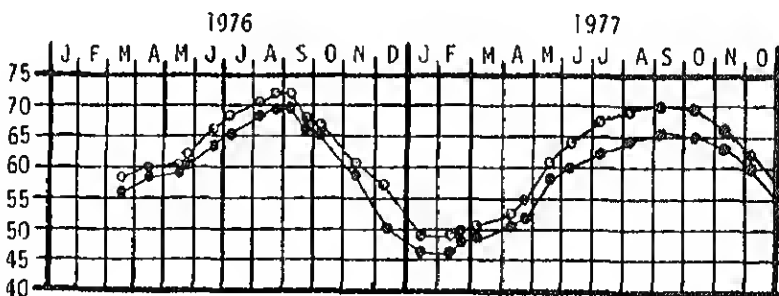
\*Depth 1



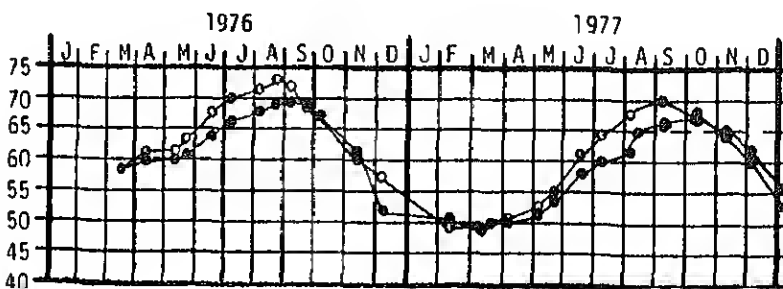
Depth 2.5



Depth 4



Depth 5.5



Soil Temperature ( $^{\circ}$  F)

variation of subsoil temperature with time and for different depths in Figure 44 . These curves exhibit the characteristic sine wave without any significant lag time from climatic conditions. Figure 44 illustrates the insulating properties of the soil by the decrease in altitude with depth. The temperature means and standard deviations test house are given in Table 25.

#### Soil Moisture-Temperature Characteristics - 4204 Culmer, Balch Springs, Texas

variation of subsoil moisture characteristics with time for this test the Taylor formation is given in Figure 45 . Data acquisition commenced on completing all actions associated with the use of a vertical barrier as a stabilization technique to inhibit moisture migration. In test house the moisture content was increased to a minimum of 2-3 above the average Plastic Limit of the soil, which was approximately 10 percent within the upper five feet. It is apparent that some adjustment was required to raise the soil moisture content from its insitu value of 17.3 percent. The maximum variation of the natural water content of soil below the Plastic Limit was 8.2 percent.

Amount of water added to the foundation soil was 13,410 gallons or 1.5 times the water added to the test house utilizing the same subsoil stabilization technique and located on the Eagle Ford formation. The characteristic dense condition of the subsoils of the Taylor formation and associated cracks and fractures caused water to be lost to significant depths without the concrete barrier. As these migration paths were gradually sealed by the expansion of the soil, the desired moisture content of the soil was achieved. After initial adjustment, the curves of Figure 45 exhibit very narrow band width and remain relatively constant with time. This indicates climatic effects are not exhibiting significant influence on soil moisture.

variation of soil temperature with time and depth is given in Figure 46. These curves show the characteristic shape without lag time. However, in Figure 46, page 96, the temperature means and standard deviations indicated by the nonoperative thermistor at the 5.5 foot depth on the West side of the test house. Consequently, the North and South side temperatures are averaged, and the second curve indicates soil temperatures of the East side only for the 5.5 foot depth of interest.

1137 Eastwood Drive, Lewisville, TX

Concrete Barrier-Water Surfactant Injection

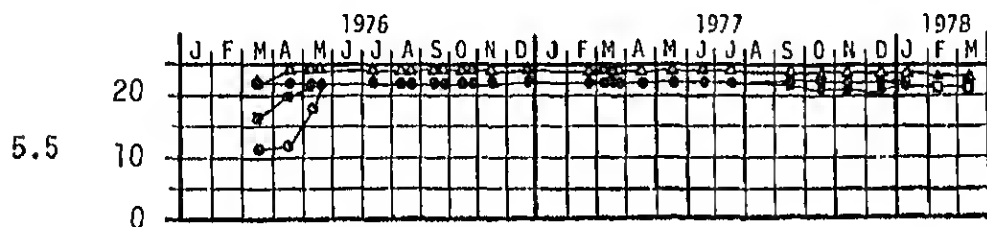
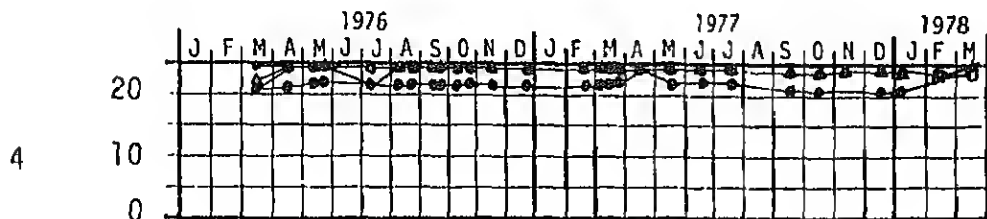
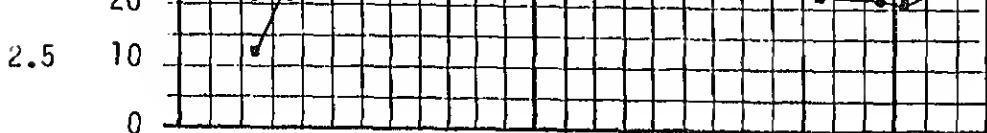
Location	*Depth (ft)			
	1	2.5	4	5.5
	58.55	60.61	58.68	59.15
	10.53	8.92	7.75	7.18
	59.95	64.00	56.56	57.53
	10.02	8.41	7.94	7.19
	64.58	60.24	63.60	64.10
	10.68	6.97	7.91	9.40
	60.53	62.98	60.70	61.10
	10.04	9.13	7.62	6.82

\*Depth refers to feet below grade beam.

4204 Culmer, Balch Springs, TX

Lean Concrete Barrier-Water Surfactant

Location	*Depth (ft)			
	1	2.5	4	
North	61.33	59.11	59.93	
	11.08	8.24	9.08	
East	60.40	62.63	61.20	
	10.28	9.30	8.65	
South	60.53	62.95	56.10	
	10.19	9.12	9.31	
West	62.18	63.72	60.98	
	9.83	8.72	8.30	



- North Side Boring
- East Side Boring
- △ South Side Boring
- West Side Boring

\* Refers to Depths Below Perimeter Grade Beam

Fig. 45 Soil Moisture Content - Lean Concrete  
4204 Culmer, Balch Springs, Texas

Investigation, natural properties of the foundation subsoil were established. Among these were the insitu moisture content averaging 13.2 percent five feet and a deviation of 8.2 percent maximum below the average Plastic Limit of 24.75 percent.

The test house at 4204 Culmer, Balch Springs, Texas, was founded on residual expansive clay soils of the Taylor formation. The soils investigation established the natural properties of the subsoil beneath the test house. These included the insitu moisture content averaging 17.3 percent at a five foot depth and having a maximum deviation of 8.2 percent below the average Plastic Limit of 20.2 percent. All soils investigations were accomplished prior to initiating stabilizing actions.

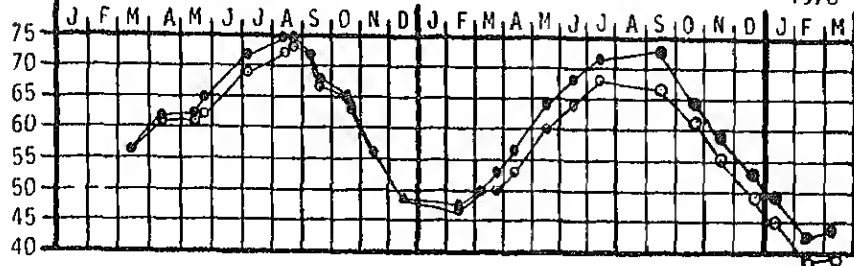
For these two test houses, the average index properties discussed are relatively close. The average insitu moisture contents being 13.2 and 17.3 percent respectively and both deviate a maximum of 8.2 percent below the respective average Plastic Limits of 24.75 percent and 20.2 percent. The average properties are to a depth of approximately five feet or the depth of the concrete moisture barrier.

For these two test locations, the amount of Montmorillonite clay minerals within the upper five feet of soil for the house located on the Eagle Ford formation is approximately 12.85 percent. The amount of Montmorillonite clay for the five feet of soil beneath the test house on the Taylor formation is approximately 39.8 percent. This amounts to a difference of 26.95 percent. This significant percentage of these highly expansive minerals, along with the method of introducing water into the foundation soils may explain the variation in moisture contents at the moisture-temperature cell locations at the two sites.

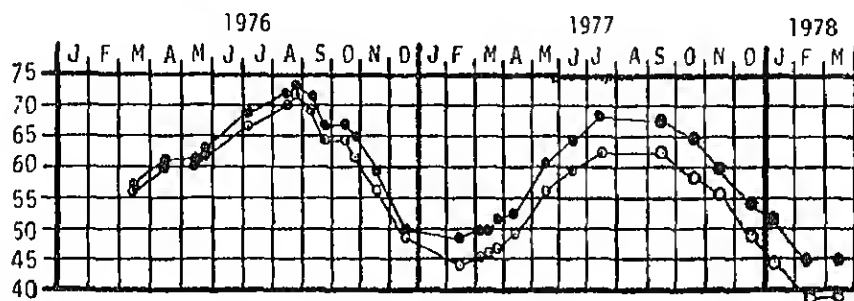
It would appear that when water is introduced around the house perimeter higher moisture contents are reflected on the installed instrumentation. Understandably, the moisture migration paths are much less and cracks and fractures provide the primary avenues of travel until swelling precludes further movement. Further moisture migration would then be a function of permeability of the soil if free water still remains available. The amount of free water would be that which could be pulled through the soil capillary forces stronger than the forces of the clay minerals in developing the double layer.

For the test house at 1137 Eastwood Drive, Lewisville, Texas, the condition of the subsoil beneath the slab interior was largely indeterminate. However, knowing the slab interior was lower than the perimeter indicated more desiccated condition. Even though, laboratory testing showed the subsoil moisture within the house interior was raised by the addition of water to the desired value, there was nothing to preclude moisture migrating downward as well as laterally. This could reduce the moisture content of the

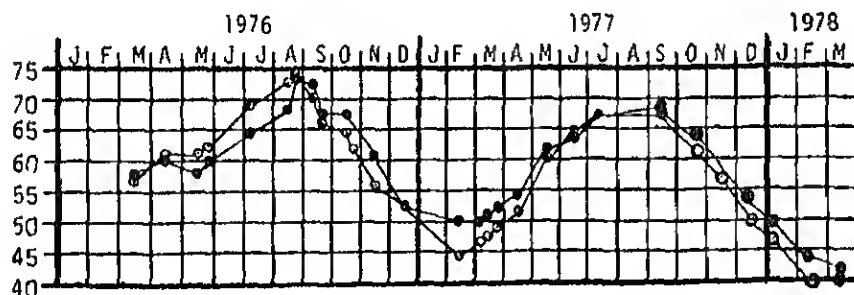
th 2.5



th 4



th 5.5



-Key-

- North and South Side Average
- East and West Side Average

pths refer to feet below grade beam.

. 46 Soil Temperature Variation  
4204 Culmer, Balch Springs, Texas

11 beneath the house as a much larger volume of soil would be included. nally, movement of water laterally to the instrumentation points could ve been restricted to a degree by the natural soil forces, and equilibrium established with different moisture contents. As the house perimeter was gher than the interior, it follows the moisture content was also higher. nsequently, the soil moisture demand would be less at the perimeter, and e forces inherent in satisfying this demand, for moisture migration from drier environment to a more moist regime would also be less.

A comparison of soil temperature variation with time from data given Figures 44 and 46, and Tables 25 and 26, pages 94, 99, and 96 e relatively similar. Any significant variation is considered due to ss of instrumentation. Figures 44 and 46 both show the same basic chara tics without significant lag time. This would infer that temperature ffects within the soil vary too rapidly to greatly effect moisture conten en enclosed by a barrier. Temperature data do indicate the effectiveness soil as an insulating medium.

## 5 EVALUATION OF VERTICAL MOISTURE MIGRATION BARRIERS

The primary purpose of the three different types of vertical moisture migration barriers was to inhibit or minimize vertical movement of the fou n subsoil. The mechanism of accomplishment was to cut the soil capilla thin the mass at the interface of soil and vertical barriers. This woul minimize moisture loss and subsequent volume fluctuations caused by climat fluence. This condition would be effected in approximately five feet of bsoil below the floor slab, causing the house structure, floor slab, and bsoil to behave as a layered system. This soil-structure interaction wo splace the plane of reference for vertical movements or volume change so ve feet beneath the bottom of the floor slab. Any vertical movement wou en be inhibited by the unit loading of the structure on the soil surface s the significant weight of five feet of soil over a unit area.

In evaluating the relative effectiveness of the three types of vertic isture migration barriers on two different geologic formations, a review l figures associated with vertical movements and differential elevations ong each side of the individual test houses reveals certain conditions ist.

The magnitude of vertical movements was not unexpected due to the dam ndition of the test houses and the volume of water required for increas o soil moisture to the desired level. Maximum differential elevation cha uld also be initially large for same reasons. Both the Eagle Ford and ylor formations were sedimentary in nature and consequently had a wide r soil particle types. Their plastic behavior, however, would classify t sidual soils, on both formations, as inorganic clays of high plasticity

the deposition process. If these clay minerals occur in pockets, they are available at one point and not another, within the subsoils of the test house, differential movements would be increased.

Generally accepted the Taylor formation would be the more active geologic units due to the high percentage of Montmorillonite within the upper five feet of soil and to significant depths. During installation of the vertical barriers it was observed that the materials contained varying amounts of fine sand and silt which affected the clay behavior to a significant degree. After water was added and differential movements would initially increase, however, the water would disperse more rapidly with time resulting in decreased soil moisture became more uniform. Consequently, it may be concluded that the vertical barriers on the Taylor formation resulted in better performance than those on the Eagle Ford formation.

See Figures 20, 22, 29, 31, 38, and 40, pages 44, 48, 52, and 86. Relative uniformity of magnitude of vertical movement was observed around the house perimeter was observed. This is a significant variable as abrupt changes in short spans result in conditions that are untenable for concrete slabs and brick veneer.

See Figures 20, 23, 30, 32, 39, and 41, pages 44, 49, 64, and 87. A comparison of these curves with time generally indicates a tendency towards stability or becoming asymptotic to a horizontal line. This is especially true for contiguous sides of the house.

See Figures 24, 33, and 42, pages 52, 70, and 89. These graphs illustrate performances of the same stabilizing technique in the two test formations. Again, these are absolute values, but indicate the relative activity of the subsoils beneath the test houses on the two formations.

A performance summary combining six test houses, three stabilizing techniques, and two formations is given in Table 27. In all instances, the vertical barriers on the Taylor formation indicate better performance in terms of minimum perimeter differential movement. It was also concluded that the procedures were viable procedures for stabilizing foundation subsoils. The final decision may be determined from economic consideration.

As stated in Section 4.1, a trenching or excavating machine is now commercially available which can dig the narrow vertical barrier trench adjacent to the perimeter of a house. Further, as the excavating machine can be offset to either side of the machine, changes in direction of the trench configurations would not be the problem they were in this study. This method would result in cost savings in excavation, labor and materials for the trench and the final foot associated with this research.



In using a capillary barrier, a homeowner may further reduce costs by personally performing part of the work. This would require having the trenching accomplished by others, ordering the computer quantity of barrier material and then placing the material and removing spoil, from the excavation project with his own resources. Naturally, this would involve considerable labor but is entirely feasible if cost is a paramount consideration.

In using a rubber barrier, certain costs could be reduced as mentioned previously. However, these could be offset by other factors. Rubber materials utilized in this study were waste products from tire recapping operations. Costs were minimal for delivering these materials to specific locations over what the cost was to haul to a disposal site. If this technique was adopted to a significant extent, recapping plants would not be an adequate source of supply. It is envisioned that a chopping plant for waste tire carcasses would be established if sufficient demand or market existed in local or regional areas. The output of the plant must provide adequate size distribution of particles to insure minimum void volume. The mixture composition used in this study was not considered the only one which could be developed, and further study may show it entirely possible to develop a mix which would not require expensive, emulsified asphalt and still achieve relative impermeability.

In using a lean concrete barrier costs would again be reduced from those indicated in Table 27, page . As relative impermeability, rather than strength, was the essential criterion, cement quantity served primarily as a binder to insure sufficient fines within the mix. Extender such as flyash, which is becoming available in greater quantities as more lignite generating stations are being placed in operation, could be utilized in part as fines to offset the increased cost of Portland cement. The installation of a concrete barrier could be accomplished in less time than the other two types. By utilizing a high slump concrete (8 inch) the mixture could flow from a delivery truck with extended chute completely around the excavation for a vertical barrier. Hand placement is only required where the barrier is not continuous, such as driveways, patios and sidewalk slabs.

VERTICAL MOISTURE BARRIER  
PERFORMANCE SUMMARY  
(January 1978)

Test House Address	For- mat- ion	Maximum Vertical Movement (inches)				Maximum Differential Movement (inches)				Maximum Perimeter Differential Movement (inches)
		North	East	South	West	North	East	South	West	
1642 Cedar Keys Dr Lewisville, Tx	EF	2.28	3.00	3.00	1.68	0.58	0.77	2.64	1.37	2.64
9909 Bluffcreek Dallas, Tx	T	3.60	3.24	3.72	3.48	0.44	0.19	1.31	0.66	1.45
461 Sweetbriar Dr Dallas, Tx	EF	2.64	2.84	2.28	1.44	1.15	0.66	0.95	0.14	1.64
1314 Athens St Mesquite, Tx	T	1.32	0.84	0.96	1.32	1.16	0.63	0.74	1.16	1.16
1137 Eastwood Dr Lewisville, Tx	EF	1.80	1.80	2.52	2.52	0.52	0.34	1.39	1.78	1.78
4204 Culmer Balch Springs Tx	T	0.84	0.72	1.14	1.14	0.36	0.38	0.71	0.41	0.83

EF - Eagle Ford Formation

T - Taylor Formation

## SUBSURFACE IRRIGATION SYSTEMS

### 5.1 GENERAL

Subsurface irrigation systems were installed under two (2) houses in order to study their suitability as a remedial measure for minimizing differential soil movement. One house is located on soils of each geologic formation under study. These systems have been utilized to continuously provide moisture to subgrades and vegetation for the purpose of stabilizing soil water contents. Once subgrade moisture contents were brought to the optimum, the available moisture should minimize further movement of the structure.

The subsurface irrigation system consisted of a continuous length of porous rubber pipe placed 6 to 8 inches below and in line with the outside edge of all perimeter foundation grade beams. The pipe was manufactured in various rates of permeability. Piping materials consisted of recycled rubber tires and recycled plastic. The pipe loop was fed from a pressure regulator placed at the water main to each house and adjusted to supply approximately one gallon per minute to the subgrade under a pressure about six (6) pounds per square inch.

As the installation of each system was complete, flow was started via the porous pipe into the relatively dry subgrades. The flow rates, as expected, were high at first and as the subsoil satisfied its moisture demand, the flow was reduced. Initially, water content of the soil adjacent to the pipe was brought up to optimum. Then, migration of moisture to distant subgrade areas occurred creating a demand for additional flow. This caused water to leak from the porous pipe. The process of gradual wetting of subgrade areas was dependent on soil properties to pull water from the pipe. At equilibrium, the system should automatically provide water to the subgrade as needed.

### 5.2 INSTALLATION

The first house around which a subsurface irrigation system was installed was located at 5807 Fess Street, in Dallas, Texas, and was founded on soil belonging to the Eagle Ford geologic formation. The other house where the system was placed in the subgrade was located at 5313 Heath Street, Mesquite, Texas, in an area underlain by the Taylor geologic formation. Details of floor plan of each house, installation procedure, instrumentation, bench leveling points costs, and soils investigation have previously been given. Further, contour maps of each floor slab, prices and subsequent to installation of the stabilization technique have also been reported. (1,2)

vertical movement is 0.00 inches.

As given in Figure 48 and Table 28, the maximum differential movement on any side of the house is 0.5 inches for January 1978. The climatic effects are also apparent with time for the approximate 2 year period or seasonal cycles associated with this technique.

The data shown in Figures 47 and 48 is even more remarkable when the problems associated with this technique were considered. This test house was vandalized on more than one occasion, water service shut off for indeterminate periods and the meter removed or stolen.

## 2.2 Vertical Movement - 3513 Heath Street, Mesquite, Texas

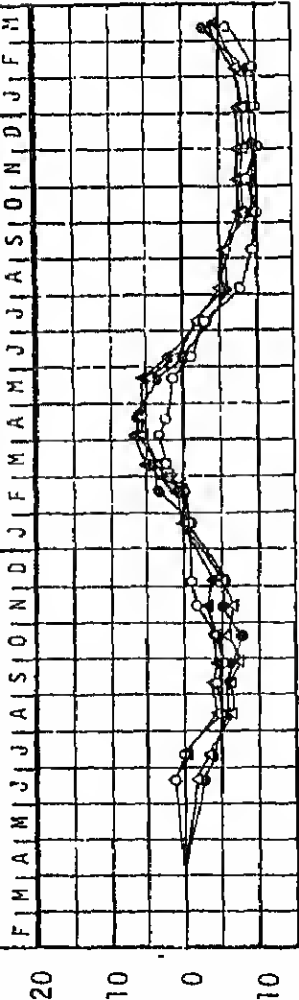
Vertical movements associated with the SIS at 3513 Heath Street, Mesquite, Texas, are given in Figure 49. These data are given for information only because the system was destroyed by the buyer who purchased the property from the U.D. Dallas area office.

Again, vertical movements with time show a distinct correlation with climatic cycles. It is evident from Figure 49 when the system ceased to function, or June 1977. Vertical movements were approximately double for this house as compared to the vertical movements associated with the test house on the Eagle Ford formation.

Differential elevations along each side of the house perimeter are given in Figure 50 and Table 29. Again this information provides a data base for two years or four seasonal cycles; however, it is not a factual indication of system performance.

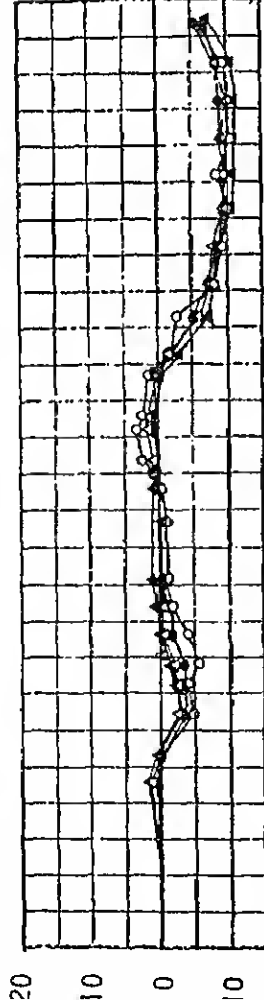
## 2.3 Comparison of Vertical Movements

Comparison of the two test houses on two geologic formations is only possible during the period of time both systems are functioning. For this period, the SIS performed remarkably well on the Eagle Ford with vertical movements being approximately one half of the vertical movements for the house on the Taylor formation. Figure 51 and Tables 30 and 31 show absolute values of movement around the perimeter of the house. The data for the house at 5807 Fess Street, Dallas, Texas is factual. The data given for



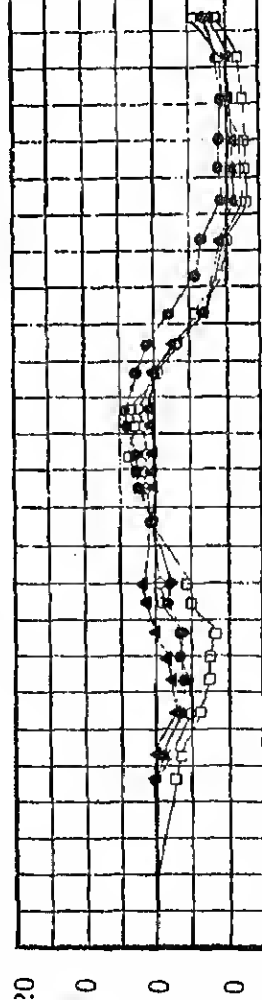
# NORTH SIDE

Level Pin 2 ●  
Level Pin 3 △  
Level Pin 4 ▲  
Level Pin 5 ○



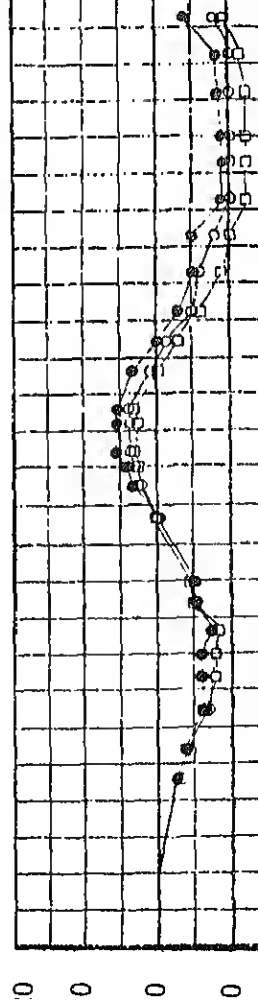
# EAST SIDE

Level Pin 5 ○  
Level Pin 6 ●  
Level Pin 7 △  
Level Pin 8 ▲



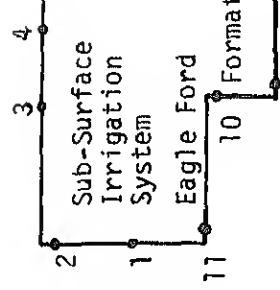
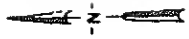
# SOUTH SIDE

Level Pin 8 ▲  
Level Pin 9 ○  
Level Pin 10 ●  
Level Pin 11 △



# WEST SIDE

Level Pin 1 ○  
Level Pin 2 ●  
Level Pin 11 △



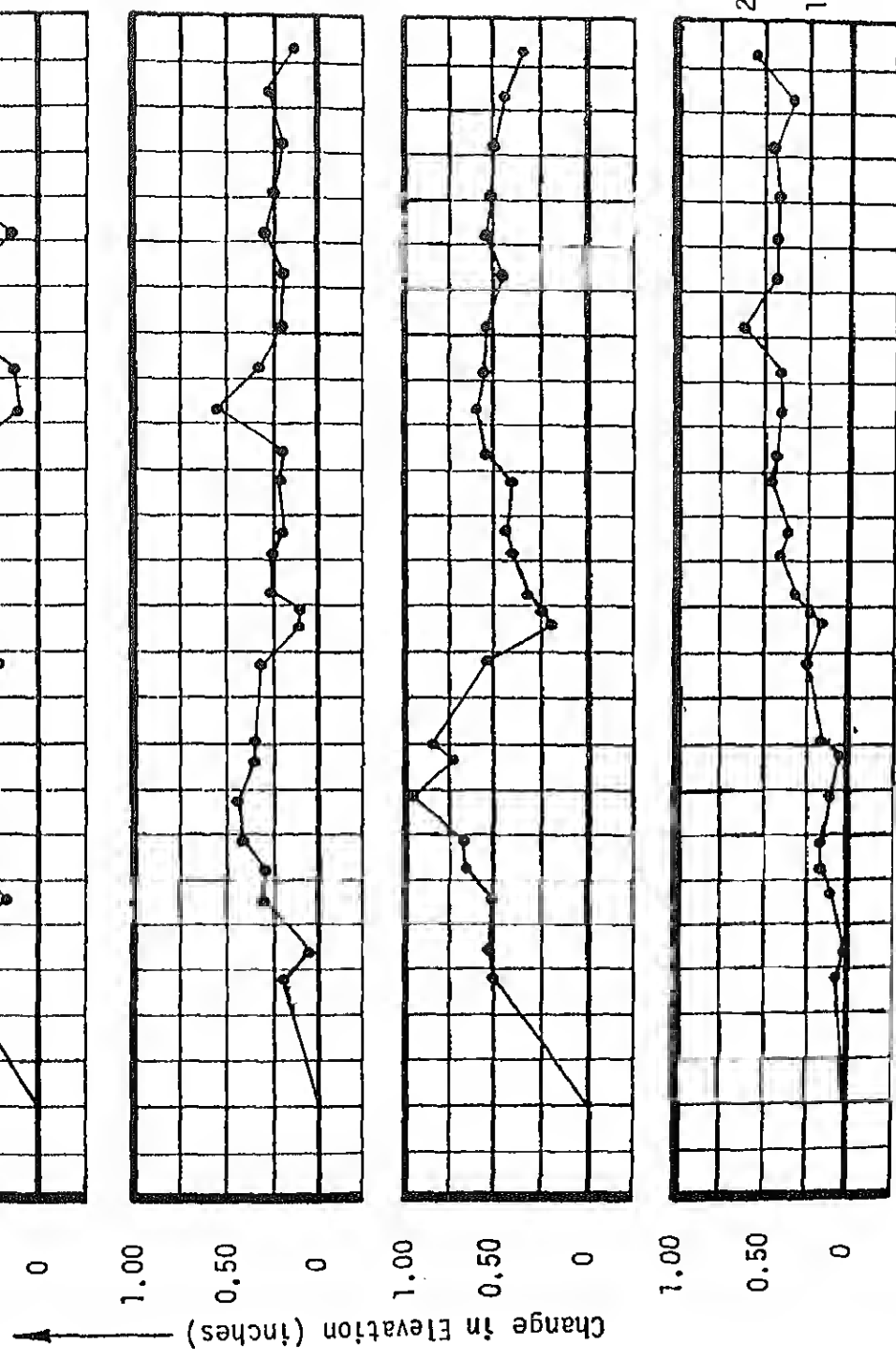
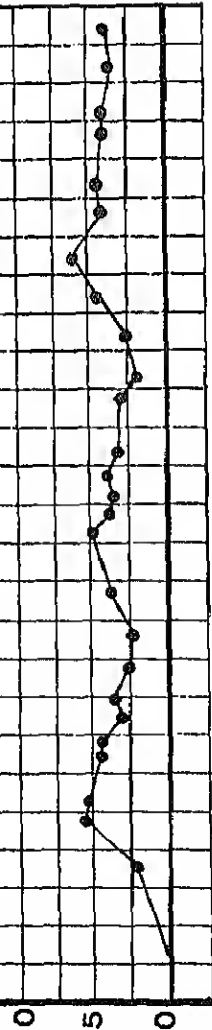


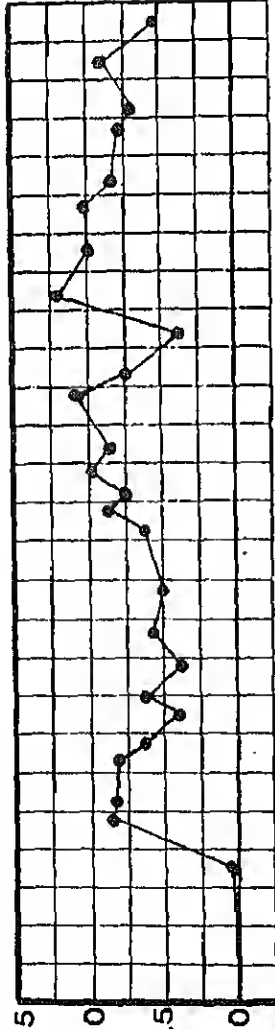
Fig. 48 Differential Elevation on Slab Perimeter  
5807 Fess Street, Dallas, Texas

# Differential Elevation: Lot

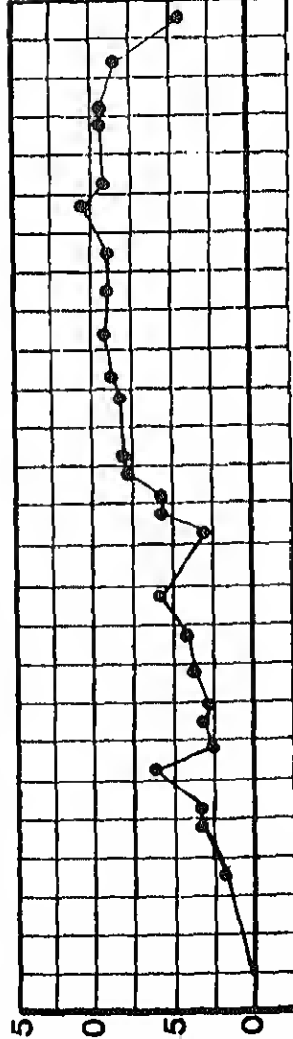
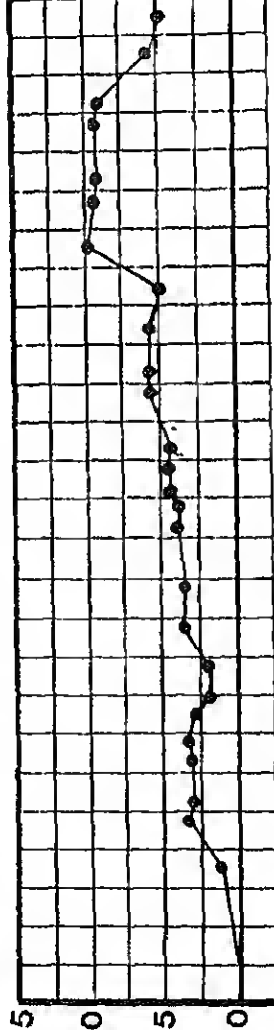
Date	North Side			East Side			South Side			West Side	
	Ft.	In.	Cm.	Ft.	In.	Cm.	Ft.	In.	Cm.	Ft.	In.
06-23-76	.037	.444	1.128	.016	.192	.488	.041	.492	1.250	.006	.000
07-09-76	.045	.540	1.372	.004	.048	.122	.044	.528	1.341	.002	.000
08-16-76	.017	.204	.518	.024	.288	.732	.042	.504	1.280	.009	.000
09-09-76	.026	.312	.792	.024	.288	.732	.055	.660	1.676	.014	.000
09-29-76	.022	.264	.671	.035	.420	1.067	.056	.672	1.707	.014	.000
10-21-76	.028	.336	.853	.036	.432	1.097	.082	.984	2.499	.008	.000
11-16-76	.042	.504	1.280	.030	.360	.914	.061	.732	1.859	.005	.000
12-02-76	.043	.516	1.311	.029	.348	.884	.071	.852	2.164	.013	.000
01-21-77	.020	.240	.610	.028	.336	.853	.044	.528	1.341	.008	.000
02-18-77	.041	.492	1.250	.010	.120	.305	.018	.216	.549	.014	.000
02-28-77	.037	.444	1.128	.009	.108	.274	.020	.240	.610	.020	.000
03-11-77	.029	.348	.884	.021	.252	.640	.028	.336	.853	.027	.000
04-04-77	.039	.468	1.189	.021	.252	.640	.034	.408	1.036	.032	.000
04-19-77	.034	.408	1.036	.015	.180	.457	.036	.432	1.097	.030	.000
05-24-77	.039	.468	1.189	.017	.204	.518	.034	.408	1.036	.040	.000
06-10-77	.036	.432	1.097	.016	.192	.488	.045	.540	1.372	.035	.000
07-08-77	.011	.132	.335	.045	.540	1.372	.050	.600	1.524	.038	.000
08-05-77	.015	.180	.457	.027	.324	.823	.047	.564	1.433	.035	.000
09-07-77	.039	.468	1.189	.017	.204	.518	.044	.528	1.341	.053	.000
10-10-77	.029	.348	.884	.017	.204	.518	.037	.444	1.128	.038	.000
11-04-77	.014	.168	.427	.025	.300	.762	.044	.528	1.341	.036	.000
12-01-77	.036	.432	1.097	.021	.252	.640	.043	.516	1.311	.035	.000
01-04-78	.029	.348	.884	.019	.228	.579	.041	.492	1.250	.037	.000
02-06-78	.026	.312	.792	.022	.264	.671	.040	.480	1.219	.031	.000
03-08-78	.022	.264	.671	.011	.132	.335	.030	.360	.914	.046	.000



East Side



South Side



West Side

8 9 10

Sub-Surface  
Irrigation System

Taylor Marl Formation

7



07-76	.049	.528	1.341	.071	.032	2.101	.026	.312	.792	.052	.624	1.5
11-76	.031	.444	1.128	.066	.792	2.012	.026	.312	.792	.052	.624	1.5
26-76	.035	.420	1.067	.054	.648	1.646	.028	.336	.853	.022	.264	.6
14-76	.024	.288	.732	.032	.384	.975	.023	.276	.701	.028	.336	.8
30-76	.028	.336	.853	.049	.588	1.494	.018	.216	.549	.023	.276	.7
22-76	.022	.264	.671	.029	.348	.884	.017	.204	.518	.033	.396	1.0
18-76	.020	.240	.610	.047	.564	1.433	.022	.324	.823	.036	.432	.0
21-76	.031	.372	.945	.041	.492	1.250	.026	.312	.792	.048	.576	1.4
07-77	.041	.492	1.250	.055	.660	1.676	.036	.432	1.097	.026	.312	.7
21-77	.033	.396	1.006	.069	.828	2.103	.033	.396	1.006	.047	.564	1.4
04-77	.028	.336	.853	.063	.756	1.920	.039	.468	1.189	.049	.588	1.4
25-77	.032	.384	.975	.081	.972	2.469	.038	.456	1.158	.061	.732	1.8
11-77	.027	.324	.823	.074	.888	2.256	.037	.444	1.128	.065	.780	1.8
23-77	.024	.288	.731	.093	1.116	2.835	.045	.541	1.372	.068	.816	2.2
09-77	.015	.180	.457	.063	.756	1.920	.046	.552	1.402	.072	.864	2.2
11-77	.022	.264	.671	.033	.396	1.006	.047	.564	1.433	.078	.936	2.2
3-11-77	.039	.468	1.189	.103	1.236	3.139	.040	.480	1.219	.076	.912	2.2
9-15-77	.050	.600	1.524	.081	.972	2.469	.081	.972	2.469	.074	.888	2.2
0-27-77	.033	.396	1.006	.087	1.044	2.652	.081	.972	2.469	.090	1.080	2.2
1-11-77	.034	.408	1.036	.067	.804	2.042	.075	.900	2.286	.080	.960	2.2
2-20-77	.028	.336	.853	.062	.744	1.890	.073	.876	2.225	.081	.972	2.2
1-05-78	.029	.348	.884	.056	.672	1.707	.069	.828	2.103	.081	.972	2.2
2-13-78	.027	.324	.823	.075	.900	2.286	.048	.576	1.463	.071	.852	2.2
3-10-78	.030	.360	.914	.046	.552	1.402	.035	.420	1.067	.039	.468	1.8

of the test house.

The plot of absolute values for the house on the Taylor formation appeared to be approaching a relative correlation of stability. This can be stated with certainty, but there is no reason to presume otherwise. Figure 51 gives an indication of the activity of the two test houses on two geologic formations and would indicate both data sets are becoming asymptotic with some perturbations, to a horizontal plane.

#### 5.2.4. Soil Moisture-Temperature Characteristics - 5807 Fess Street, Dallas, Texas

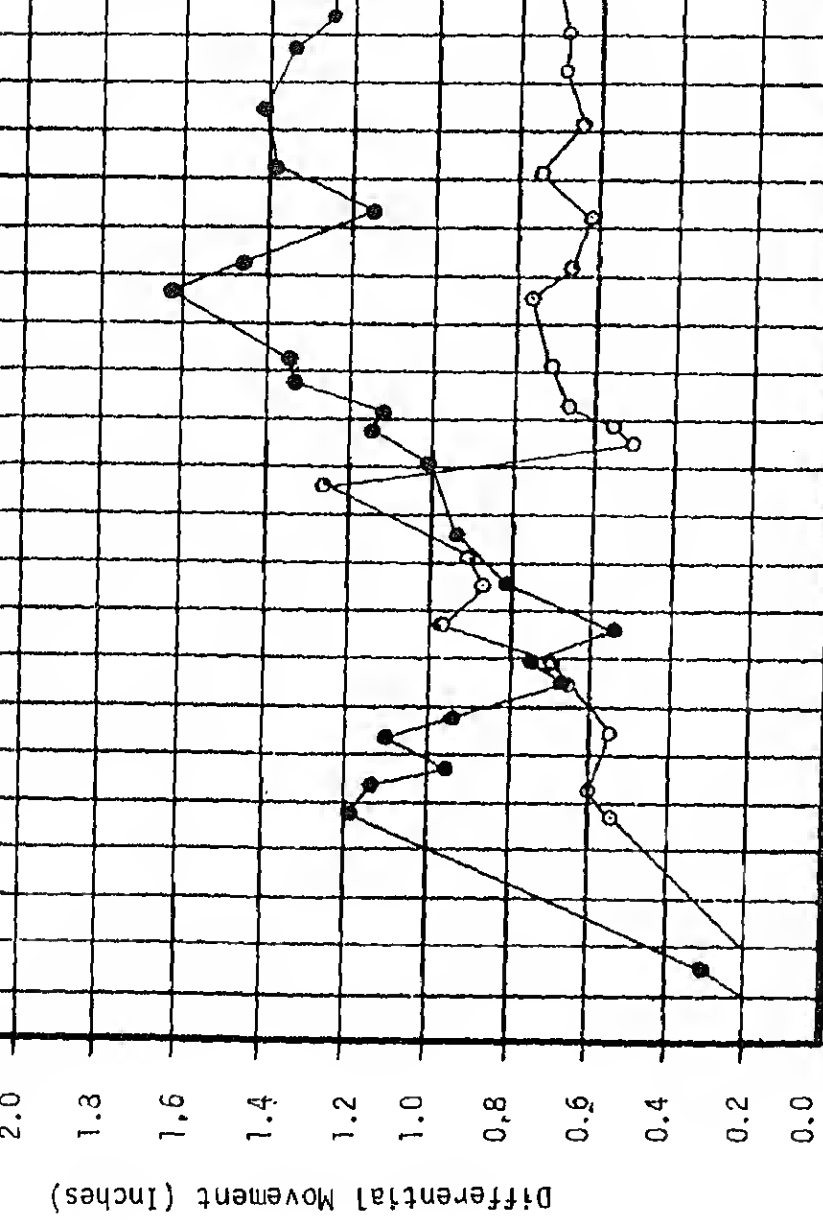
The action of adverse climate is known to initiate soil volume change with time, and corresponding vertical movement. The subsoil moisture data as given in Figure 52 vividly show the effects of climate on moisture stability in a subsoil. The extreme variation with time on all sides of the house and most depths indicates climatic influence over soil moisture.

For the test house at 5807 Fess Street, Dallas, Texas, a large cotton tree was located in the proximity of the Northeast corner of the house, and the remainder of the yard was barren. The moisture-temperature cells were installed in borings at the midpoint of each side of the perimeter. A much wider variation in moisture contents at all depths was observed for the instruments in the North and East side borings. This increased magnitude of variation is not considered due entirely to climate when considering the remaining curves. It is believed the root system of the tree is magnifying climatic effects particularly at the lower depths of interest.

Subsoil temperature variations with time and depth are given in Figure 53. These data give an excellent indication of climatic effects on subsoil temperature variation. The curves have the characteristic sine wave shape without lag time and the curve amplitudes decrease with depth of soil cover. Temperature means and standard deviations are given in Table 32.

#### 5.2.5. Soil Moisture-Temperature Characteristics - 3513 Heath Street, Mesquite, Texas

The moisture data given in Figure 54 do not show the extreme variation for this test house as it did for the house on the Eagle Ford f



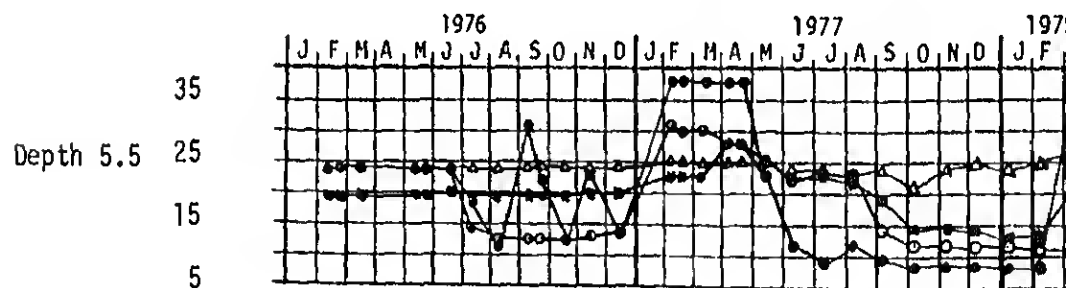
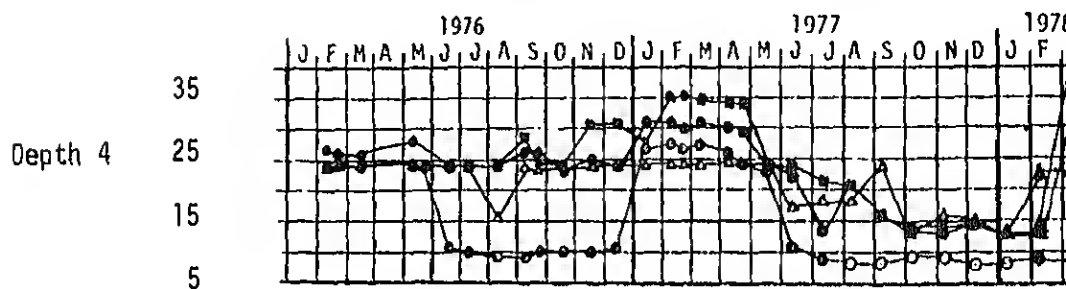
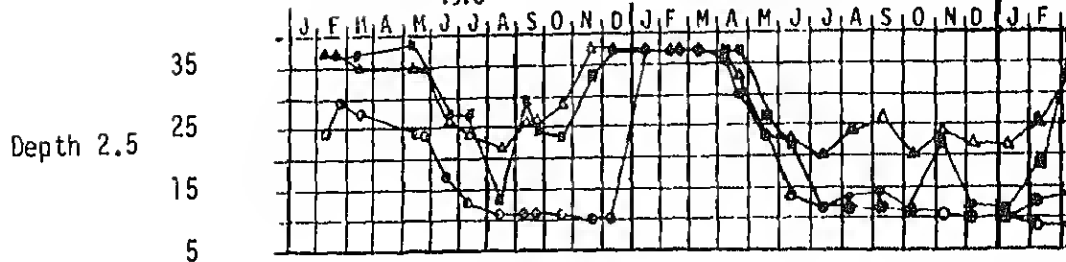
○ 5807 Fess Street, Dallas, Texas - Eagle Ford Form  
 ● 3513 Heath Street, Mesquite, Texas - Taylor Marl F

Fig. 51 Maximum Perimeter Differential Movement Comparison on  
 Different Geologic Formations Sub-Surface Irrigation Sys

Date	Movement		
	Feet	Inches	Cm.
June 23, 1976	.047	.564	1.433
July 9, 1976	.050	.600	1.524
Aug. 16, 1976	.046	.552	1.402
Sep. 9, 1976	.055	.660	1.676
Sep. 29, 1976	.059	.708	1.798
Oct. 21, 1976	.082	.984	2.499
Nov. 16, 1976	.072	.864	2.195
Dec. 2, 1976	.074	.888	2.256
Jan. 21, 1977	.104	1.248	3.170
Feb. 18, 1977	.042	.504	1.280
Feb. 28, 1977	.046	.552	1.402
Mar. 11, 1977	.055	.660	1.676
Apr. 4, 1977	.060	.720	1.829
May 24, 1977	.064	.768	1.951
June 10, 1977	.055	.660	1.676
July 8, 1977	.051	.612	1.554
Aug. 5, 1977	.062	.744	1.890
Sep. 7, 1977	.053	.636	1.615
Oct. 10, 1977	.057	.684	1.737
Nov. 4, 1977	.057	.684	1.737
Dec. 1, 1977	.059	.708	1.798
Jan. 4, 1978	.053	.636	1.615
Feb. 6, 1978	.050	.600	1.524
Mar. 8, 1978	.046	.552	1.402

## Maximum Perimeter Differential Movement

Date	Movement		
	Feet	Inches	Cm.
Mar. 16, 1976	.024	.288	.732
June 25, 1976	.099	1.188	3.018
July 7, 1976	.095	1.140	2.896
Aug. 11, 1976	.092	1.104	2.804
Aug. 24, 1976	.077	.924	2.347
Sep. 14, 1976	.055	.660	1.676
Sep. 30, 1976	.063	.756	1.920
Oct. 22, 1976	.046	.552	1.402
Nov. 18, 1976	.067	.804	2.042
Dec. 21, 1976	.078	.936	2.377
Feb. 7, 1977	.084	1.008	2.560
Feb. 21, 1977	.096	1.152	2.926
Mar. 4, 1977	.094	1.128	2.865
Mar. 25, 1977	.111	1.332	3.383
Apr. 11, 1977	.113	1.356	3.444
May 23, 1977	.135	1.620	4.115
June 9, 1977	.122	1.464	3.719
July 12, 1977	.096	1.152	2.926
Aug. 11, 1977	.116	1.392	3.536
Sep. 15, 1977	.117	1.404	3.566
Oct. 21, 1977	.111	1.331	3.383
Nov. 11, 1977	.104	1.248	3.170
Dec. 20, 1977	.104	1.248	3.170
Jan. 5, 1978	.099	1.188	3.018
Feb. 13, 1978	.093	1.116	2.835
Mar. 10, 1978	.076	.912	2.316

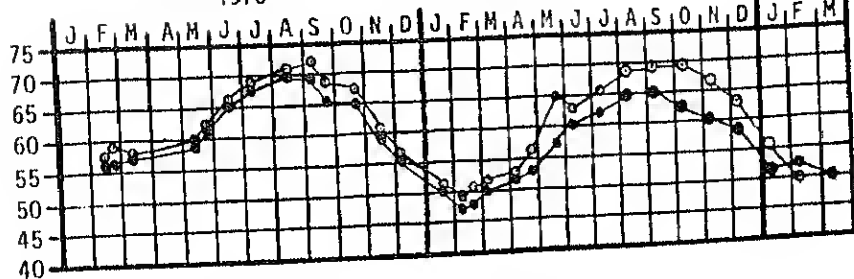


- North Side Boring
- East Side Boring
- △ South Side Boring
- West Side Boring

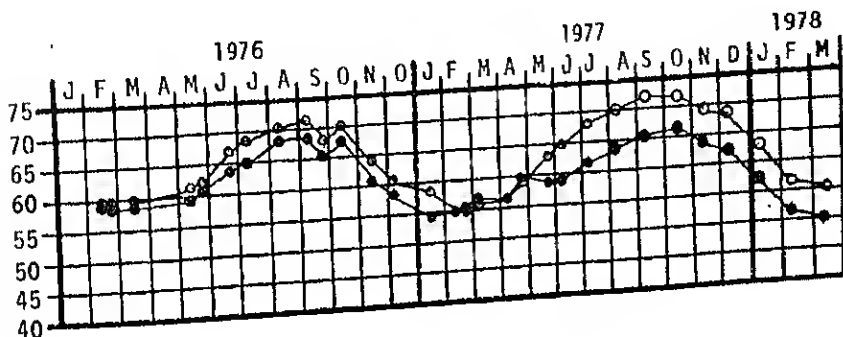
\* Refers to Depths Below Perimeter Grade Beam

Fig. 52 Soil Moisture Content - Subsurface Irrigation System - 5807 Fess Street, Dallas, Texas

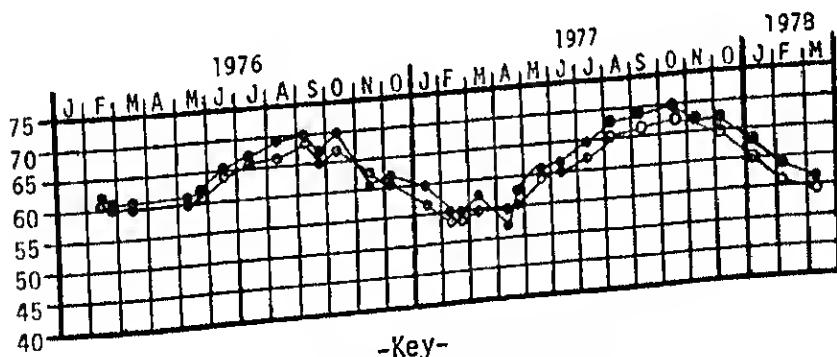
Depth 2.5



Depth 4



Depth 5.5



-Key-

- North and South Side Average
- East and West Side Average

\*Depths refer to feet below grade beam.

Fig. 53 Soil Temperature Variation  
5807 Fess Street, Dallas, Texas

SIS

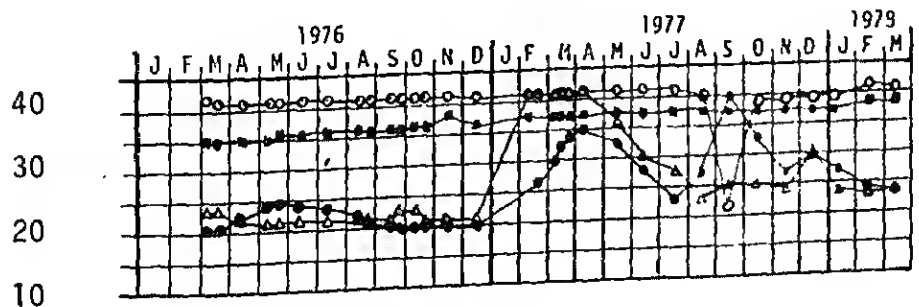
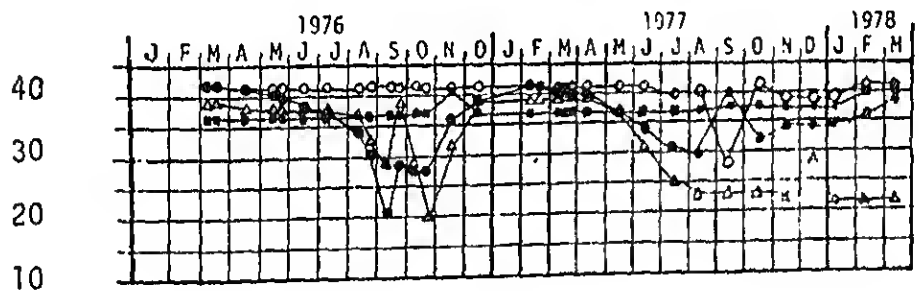
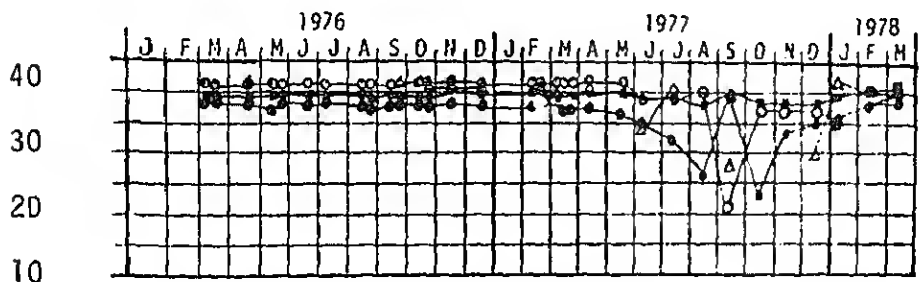
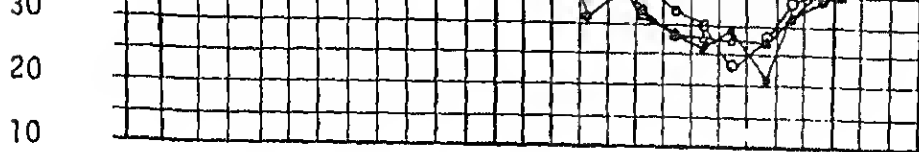
Cell Location	*Depth (ft)			
	1	2.5	4	5.5
North	59.45 9.14	58.20 7.28	60.85 5.82	60.20 5.02
East	63.88 8.29	62.15 6.71	59.90 5.53	61.10 4.47
South	63.25 8.55	63.55 7.15	64.83 5.58	60.95 4.58
West	60.64 8.68	55.05 7.47	59.15 5.88	63.25 5.94

SIS

Location	*Depth (ft)	
	1	2.5
North	62.68 8.76	60.86 7.10
East	58.39 8.60	59.23 7.18
South	60.32 8.25	dead
West	63.74 7.26	62.65 5.39

\*Depth refers to feet below grade beam.



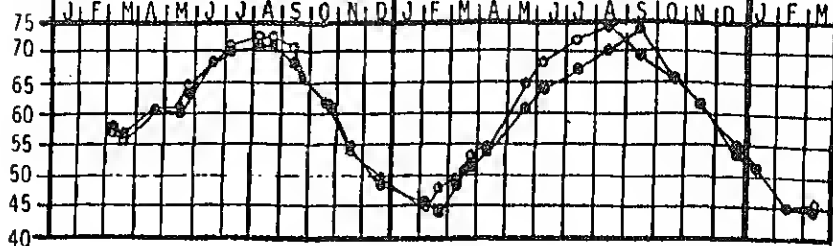


- North Side Boring
- East Side Boring
- △ South Side Boring
- West Side Boring

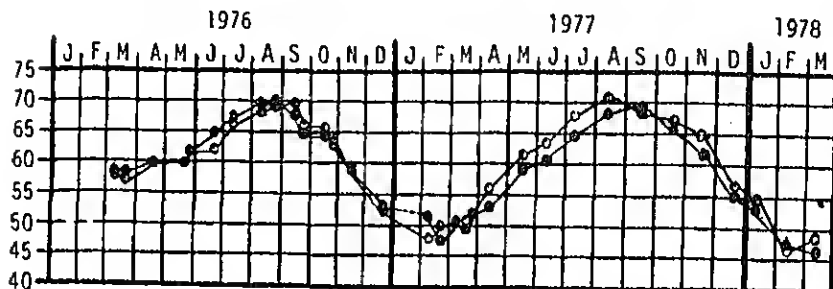
\* Refers to Depths Below Perimeter Grade Beam

Soil Moisture Content - Sub-Surface Irrigation

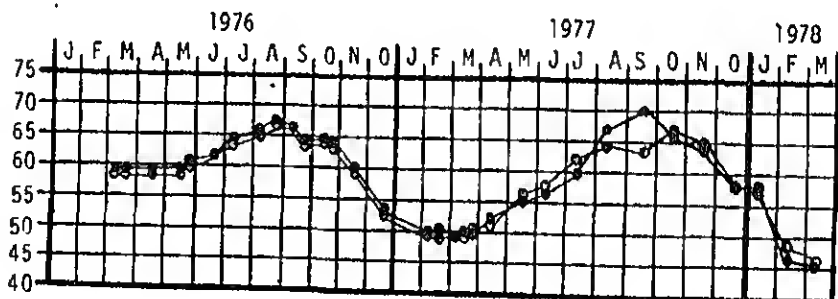
\*Depth 1



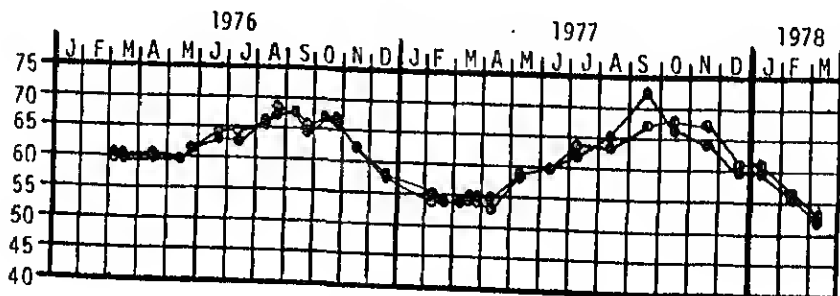
Depth 2.5



Depth 4



Depth 5.5



-Key-

o North and South Side Ave

sly been noted that this formation was dense and contained cracks and fractures. Further, the soil within the depths of fine sand and silt materials. Consequently, water could not be utilizing fracture paths initially. As these avenues closed, water through the subsurface soils would depend on the soil permeability for adequate distribution. The mixture of silts and sands within the soil provide the soil matrix with a higher permeability and more water migration. This condition is indicated with exceptions by the curves indicated by depth 4, the anomaly indicated by wells on the East and West sides of the test house are considered factors. These significant variations in moisture contents within the periods and at such a depth would not occur so abruptly.

Data given in Figure 54 are appropriate only for the time the subsurface irrigation system was operative. Beyond that time, data values reflect effects modified by a foundation watering program the new test house initiated after discussion with research personnel.

Temperature variations with time and depth are given in Figure 55. The characteristic shape with time and depth is again noted. The instruments used in the subsoils for this test house location are operative, but the subsurface irrigation system was destroyed. Consequently, it is now conclusively that soil temperature may be considered a function of climatic temperature cycles and moisture movement into or out of the soil as little, if any, effect. The values for temperature means and standard deviations are given in Table 33, page 118.

### Comparison of Moisture-Temperature Characteristics

The premise in the use of a subsurface irrigation system as a subsurface irrigation technique for expansive clay soils was to install and operate a system which would introduce water into the subsoil at initially high rates which would diminish as soil moisture demand was satisfied. Water would be available for the soil, if required, but would not be available to the soil under pressure.

The investigation established among the index properties an initial moisture content of 24.2 percent at the test house at 5807 Dallas, Texas. The average Plastic Limit was 24.5% with a minimum content below the Plastic Limit of approximately 5%. The Plastic Limit of Montmorillonite clay mineral was 25.8%. All of these values for a soil depth of five feet. The relatively close initial water content and Plastic Limit again illustrates the effectiveness of the system in causing the soil to give up and take in significant water as indicated in Figure 52, page 116. It is also noted that

... cottonwood tree at the Northeast corner of the house augmented climatic effects in taking a significant percentage of water from the soil.

The effects of climate are not as extreme at the test house at 3513 Heath Street, Mesquite, Texas. The soils investigation established among index properties a natural moisture content of 29.5%. The average Plastic Limit was 31.8% and the maximum deviation of moisture content was 15%. These values are for the upper five feet of soil. It should be noted that the deviation of moisture content given was for the upper one foot of soil. Below the depth the average moisture content of the soil was 32.3 or slightly above the average Plastic Limit of 31.8%. The average percent of moisture was 32.3 within the depths of interest of the soil. As the subsurface irrigation system was installed at the approximate depth of moisture deficit it would follow the moisture content would be raised to the soil moisture demand requirement and remain stable while the system was operative as shown by Figure 54, page 119. At other depths of interest, more variation occurred however, as the natural moisture content existed above the Plastic Limit the demand would be less. This variation, at the lower depths, while the system was in operation, could be caused to some degree by climatic effects but may be primarily due to variations in subsoil properties.

A comparison of the variation in subsoil temperature with time and depth for the two test houses indicate excellent agreement as shown in Figures 53 and 55 pages 117 and 120. These two test houses are separated by a number of miles and located on different geologic formations which supports the contention that variations in soil temperatures and the insulating properties of soil are a direct function of climatic temperatures. Tables 32 and 33, page 121, give the values of temperature means and standard deviations at all depths of interest for these two test houses.

### 3. EVALUATION OF SUBSURFACE IRRIGATION SYSTEM STABILIZATION

The primary purpose for use of the subsurface irrigation stabilization technique was to determine if a relatively low cost system could be utilized along with the known characteristics of expansive clay soils to inhibit or minimize volume change due to climatic conditions. This would limit volume change and accompanying differential movements in the perimeter subsoils. As evaluation would be a minimum for installation, much of the work involved could be accomplished by a home owner who is experiencing damage to his house by vertical movements associated with expansive clay soils.

For this stabilization process, water was not introduced into the foundation soils by intent. It was desired to determine if the expansive soils could imbibe sufficient water to reach an equilibrium condition and then only take water from the system as necessary to fill the moisture demand of the soil. The concept as developed would appear to be valid, and damage reversal could be initiated for house slab movements where the perimeter beam is lower than the slab interior. The two test houses at 3513 Heath Street and 3513 Heath Street

...play a significant role in reaching a stable  
for this technique. Consequently, it was established that com-  
ation of the subsoil was not possible with this technique.  
movements above and below an equilibrium or stabilization con-  
tively small, they are not totally eliminated.

a number of problems associated with the use of this stabili-  
e. One of the problems was a control system for water pressure  
w. For this technique to be viable, the system would essen-  
be tamper proof. Another problem for consideration would be  
errupted water service to a house having this type of subsoil  
system. During the period of this research program, water ser-  
upted on many occasions, and the system was essentially de-  
test house at 5313 Heath Street, Mesquite, Texas. Finally,  
r of this porous rubber pipe has gone out of business in the  
th area and it is not known if any source of supply exists.

for utilizing this stabilization technique are relatively low.  
neal foot of house perimeter at 5807 Fess Street, Dallas, Texas  
cost per lineal foot of house perimeter at 3513 Heath Street,  
was \$3.78. Both cost figures could be reduced significantly  
accomplishing the excavation and backfilling required to bury  
the perimeter.

ferential movements associated with climatic effects were  
a sufficient market could be developed to warrant manufacture  
ipe, then perhaps additional consideration could be warranted.  
owever, the use of porous rubber pipe as a subsoil stabliza-  
is not justified.

## SUMMARY AND CONCLUSIONS

### 6.1 SUMMARY

The primary objective of this research project, identified as Phase HUD Contract H-2240R, was to investigate certain remedial techniques which could be used to restore houses damaged by foundation movements caused by expansive clay soils. All techniques were directed towards stabilizing mass of soil beneath the house floor slab to a depth of five feet or more. Both equipment and materials utilized for the subsoil stabilization techniques investigated were readily available to a contractor to determine economical alternatives. Further, consideration was given to certain techniques and to portions of the work a homeowner could accomplish to reduce costs and protect his investment.

The ten (10) houses included in this investigation were HUD owned properties that were sold upon completion of actions associated with a remedial technique. Deed restrictions permitted continued data acquisition for the duration of the contract. The houses included in this study were identified by the HUD Dallas Area Office, and all were severely distressed by vertical movement of the foundation soil resulting from volume change. The amount of volume change was largely a function of the expansive clay soils of a particular geologic formation and the climate of the area.

The Dallas-Fort Worth metroplex area has a semi-arid climate. Lengthy hot and dry periods with little or no rainfall followed by cool or cold weather periods provide the environment for expansive clay soils to manifest their destructive shrink and swell properties.

Five of the houses in this investigation were sited on the residual clay soils of the Eagle Ford geologic formation and the other five were located on the residual clay soils of the Taylor geologic formation. Both geologic formations are noted for their expansive clay soils. Further, the residual clay soils for both formations are from the Gulf Series of the Cretaceous Age and are neritic marine deposits. Volcanic materials are prominent and in particular the high percentage of Montmorillonite Clay minerals at shallow depths formed by weathering of ash.

The success, or failure, of a particular soil stabilization technique in mitigating soil volume fluctuations in the foundation subsoil was a time dependent process. Data acquisition continued over approximately two years or four seasonal climatic cycles, at which time a determination was made of the effectiveness of each technique. A stable condition was being approached for the subsoil if apparent behavior would allow the soil to interact as a mass to interact as a mass.

minimum volume configuration.

wing comments summarize the relative effectiveness of each  
stabilization technique to minimize volume change of the expansive  
the two geologic formations.

Slurry Pressure Injection: If for no other reason the high  
this technique makes it uncompetitive with other methods. The  
lineal foot of house perimeter was \$26.49 for the house at  
32nd Street, Grand Prairie, Texas, and the cost per lineal  
house perimeter was \$28.27 for the house at 2710 Cary Drive,  
Texas. The large differential movements and soil moisture  
fluctuations with climatic conditions, and without a lag time,  
a barrier to inhibit moisture migration was not provided. This  
was justified by comparing moisture data from the instruments  
in a boring placed well outside the injected area, with  
content variations from instruments inside the injected area.  
Instruments were placed at equivalent depths in the soil. It was  
that the lime slurry pressure injection process was not an  
stabilization technique for houses damaged by expansive clay

Capillary Barriers: The use of this technique for stabilization  
of subsoils for homes damaged by expansive clay soils appeared  
a viable technique. A definite factor in favor of this method was  
the amount of cost reduction possible depending on the amount  
a homeowner would contribute. The ultimate situation would  
be the services of a trenching company to dig the narrow  
excavation around the house and delivery of graded capillary  
material. A summary of performance of this stabilization techni-  
all as other vertical moisture barriers is given in Table 27, page  
values given are maximum values for January 1978, for comparison  
Detailed review of this technique as presented in Section 4 is  
The figures on vertical movements around house perimeters  
uniformity of movement between leveling points, and for the test  
Cedar Keys Drive, Lewisville, Texas, the cost for installation  
stabilizing technique was only \$3.31 per lineal foot of house  
For the test house at 9909 Bluffcreek, Dallas, Texas, the  
\$3.71 per lineal foot of house perimeter. It is noted that  
are first time application costs for this research effort.  
Previously, these costs would be reduced due to the increased  
availability of trenching equipment now available.

viable technique. However, homeowner participation, primarily involving removal of spoil resulting from the excavation process. To install this vertical barrier, as accomplished in this research program, specialized equipment is essential. Consideration is warranted for a simpler formulation of barrier mixture. The basic material of chopped-up rubber tire carcasses would still be considered as the basic aggregate, however, testing for other binding agents needs to be accomplished. Particularly, an alternate material to emulsified asphalt needs to be developed since it is expensive and difficult to work. The primary objective is relative impermeability. The strength of the membrane is not an essential consideration.

Table 27, page 101, show data values for the houses treated by this stabilization technique as the maximum values for January 1978. Data showing variations of foundation movements with time indicate the techniques effectiveness. The relative uniformity of vertical movement between leveling points around the house perimeter are indicative of technique effectiveness. These data are reinforced by the figures relating to subsoil moisture content variations with time and depth. Data reflecting narrow band widths with time, for all depths of interest, indicate relative stability, or negative influence of the climatic cycles. For the test house at 461 Sweetbriar Drive, Lewisville, Texas, the cost of the rubber barrier was \$5.41 per lineal foot of house perimeter. For the house at 1314 Athens Street, Mesquite, Texas, the cost was \$5.79 per lineal foot of house perimeter. Again, the costs given could be reduced by use of modified trenching equipment now available to the building industry.

The introduction of water to the foundation subsoils surrounded by a rubber vertical barrier could be accomplished by a homeowner. A small diameter hole could be punched through the barrier at intervals. A commonly available root feeder injection lance could be inserted into the subsoils beneath the perimeter beam for water injection. As numerous applications of water would be required, the holes could be temporarily plugged by tapered wooden dowels. After relative stability is achieved, the holes could be permanently sealed with a rubber caulking compound.



pen barrier and concrete barriers. The use of a lean concrete barrier to mitigate climatic effects and attendant of foundation subsoils was considered to be a viable stabilizing technique. A limited amount of homeowner cost reduction could be achieved by removal of spoil material from trench excavation. The barrier could be installed more effectively by utilizing readymix concrete equipped with extended delivery chutes. Strength is not a problem, so a low cement ratio could be utilized with care to insure sufficient fines in the mix for a minimum void content to insure a minimum cost to the homeowner.

Data from Table 27 for the two houses using this stabilization technique show the maximum values for January 1978. All values given in Table 27 are for comparison. However, the data values varying with vertical movements and differential movements are given in detail and indicate the technique effectiveness. The uniformity of movements between leveling points around the perimeter of the house are excellent performance indicators. This performance is confirmed by the figures indicating the stability of subsoil movements with time at all depths of interest.

For the house at 1137 Eastwood Drive, Lewisville, Texas, the cost of this technique was \$4.75 per lineal foot of house perimeter. For the house at 4204 Culmer, Balch Springs, Texas, the cost was \$4.54 per lineal foot of foundation perimeter. These costs would be reduced by the reasons given in Paragraph c.

Prevention of water into the foundation subsoils could be achieved by the homeowner in a similar manner as that described for the barrier discussed in Paragraph c above. However, adding water would be drilled through the barrier or pre-drilled dowels while the concrete was still plastic.

Irrigation System: The installation of the subsurface irrigation system to stabilize the subsoils beneath a house subjected to movements resulting from soil volume changes induced by climatic conditions was not completely effective. Differential movements around the house perimeters, but climatic effects are relatively stable value and vertical movements become relatively stable. The magnitudes of vertical movement would appear to be a minimum, but the floor slab will undergo flexure which climatic changes.

A low cost system for which the cost of installation could be reduced by a homeowner. This would include all excavation and labor required to install the system. The house at 1137 Eastwood Drive, Dallas, Texas, cost \$2.70 per lineal foot of house perimeter. For the house at 2513 Heath Street, Mesquite, Texas,

Considerable difficulty was experienced during the period of the study in keeping the system in operation at both test houses. There were indeterminate periods of time when outages occurred at each location due to vandalism, water shutoffs, and ultimately system destruction during August 1977, for the house at 3513 Heath Street, Mesquite, Texas.

The subsurface irrigation system must be considered an active system as opposed to a passive system as discussed in paragraphs b, c, and d above, as mechanical components are required to function properly for a successful system. This was found to be undesirable as there are too many ways to tamper with, or defeat the system. There are too many problems inherent in such a system at this time, and climatic cycle influence is still associated with the foundation subsoils. The subsurface irrigation system cannot be considered a realistic stabilization technique for houses damaged by expansive clay soils.

For all techniques discussed in paragraphs a through e above, data collection has continued over approximately two years or four seasonal climatic cycles. These data include vertical movements referred to a permanent benchmark, subsoil moisture at various depths and subsoil temperature at equivalent depths. By various presentations or interpretations of data, it was apparent that achieving soil stability was a time dependent process, as was the data condition associated with the shrink and swell process of expansive clay.

## 2 CONCLUSIONS

This two year study of methods to restore houses damaged by actions associated with expansive clay soils to a usable condition indicates certain tentative conclusions.

House and yard maintenance were considered directly related to the magnitude of house damage caused by differential vertical movement. The magnitude of these movements is a time dependent process which is influenced by the severity or extremes of the climatic cycle. This influence can be modified by providing adequate water to areas around the house. The amount of water for the necessary watering program would be dependent on those sides of the house subjected to the greatest severity of the climatic drying cycle and location and number of trees.

The addition of water to foundation subsoils was not and could not be expected to completely eliminate prior movements associated with shrink and swell actions. This process is not a linear type relationship, and as the type soils shrink a reorientation of the clay minerals occurs. When a swelling cycle is initiated, water will be taken into the double layer of the expansive clay minerals. However, these minerals will not return to their original positions due to some interlock of soil particles and the inherent

shed by the availability of trenching equipment. Consequently, question whether a deeper barrier would function better, or a shallower depth with reduced cost would perform as well as those. Further, it was concluded that other type barriers utilizing other material could be developed which would also accomplish the in-pose. However, this research effort was to utilize common materials ques by which the cost could possibly be reduced by homeowner par-. It is not believed, that the capillary barrier will be a deter-ot systems from trees crossing the barrier to obtain desired mois-the foundation subsoil.

the results of this research it was concluded the use of a vertical apillary or relatively impermeable, is a viable concept to stabilize subsoils from volume changes resulting from climatic cycles. Along barrier, the moisture content of the subsoils must be raised the 3 percent above the average Plastic Limit of the subsoils down to of the barrier. This action will place the mass of subsoil in a able moisture regime whereby the volume change of the soil mass ess than five percent of its total potential. The addition of he subsoil will cause the soils to increase in volume and displace erimeter upwards. Low perimeter edges would be the normal distress his area. The amount of time for the soil mass encompassed by the reach a stable condition is a function of the expansive soil pro-d how fast the added water will diffuse through the soil to approach rium condition. The end result would be for the damaged house and soil to behave as a single entity whereby this condition would be o remain essentially constant. This would permit cosmetic repairs cted, both inside and outside the damaged structure, and restora-usable condition.

Interim Report of Remedial Measures for Houses Damaged by Expansive  
Department of Housing and Urban Development, Office of Policy Development and Research; Division of Energy, Building Technology, and Standards  
Washington, D. C., October, 1975.

Interim Report of Remedial Measures for Houses Damaged by Expansive  
Department of Housing and Urban Development, Office of Policy Development and Research; Division of Energy, Building Technology, and Standards  
Washington, D. C., November, 1976.